Non-Water Quality Impact Estimates for Animal Feeding Operations

U.S. Environmental Protection Agency
Engineering and Analysis Division
Office of Water
1200 Pennsylvania Avenue, NW
Washington, D.C. 20460

December 2002

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Prepared for:

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December 2002

ACKNOWLEDGMENTS AND DISCLAIMER

This report was prepared by Eastern Research Group, Inc., under the direction and review of the Office of Science and Technology.

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1.0 INTRODUCTION

Eliminating or reducing one form of pollution may create or aggravate other environmental problems. Sections 304(b) and 306 of the Clean Water Act (CWA) require that the U.S. Environmental Protection Agency (EPA) consider the non-water quality environmental impacts (NWQI) of effluent limitations guidelines and standards (ELGs). This report presents the methodology and estimates of the NWQI for seven regulatory options that were considered for concentrated animal feeding operations (CAFOs), including beef feedlots, dairies, and heifer, veal, swine, broiler, layer, and turkey operations. The impacts include:

- Air emissions from the animal production area, including animal housing and manure storage and treatment areas;
- Air emissions from the application of manure to land;
- Air emissions from vehicles, including those involved in the off-site transport of manure and in on-site composting operations; and
- Energy impacts from land application activities, the use of digesters, and the transportation of manure.

Typically, NWQI also include estimates of the generation of solid waste. Because manure is considered a by product of animal feeding operations with resource value and is not regulated directly, the solid waste NWQI of the manure are not considered. In addition, although the chemical content of the manure may change, the amount of manure generated is not expected to change significantly under any of the regulatory options being considered; therefore, a discussion of solid waste NWQI is not included in this report.

1.1 Pollutants Considered

A number of factors affect the emission of pollutants from CAFOs and their use of energy. Most of the substances emitted are the products of microbial processes that decompose the complex organic constituents in manure. The microbial environment determines which substances are generated and at what rate. This section describes the chemical and biological mechanisms that affect the formation and release of emissions. The pollutants included in this analysis are:

- Ammonia. Ammonia is a by-product of the microbial decomposition of the organic nitrogen compounds in manure. Nitrogen occurs as both unabsorbed nutrients in manure and as either urea (mammals) or uric acid (poultry) in urine. Urea and uric acid will hydrolyze rapidly to form ammonia and will be emitted soon after excretion. Ammonia will continue to form during with the microbial breakdown of manure under both aerobic and anaerobic conditions. Because it is highly soluble in water, ammonia will accumulate in manure handled as liquids and semi solids or slurries, but will volatilize rapidly with drying from manure handled as solids. Therefore, the potential for ammonia volatilization exists wherever manure is present, and ammonia will be emitted from confinement buildings, open dry lots, stockpiles, anaerobic lagoons, and land application from both wet and dry handling systems.

  The volatilization of ammonia from CAFOs can be highly variable depending on total ammonia concentration, temperature, pH, and storage time. Emissions will depend on how much of the ammonia-nitrogen in solution reacts to form ammonia versus ionized ammonium (NH_4^+), which is nonvolatile. In solution, the partitioning of ammonia between the ionized (NH_4^+) and un-ionized (NH_3) species is controlled by pH and temperature. Under acidic conditions ($pH<7.0$) ammonium is the predominant species, and ammonia volatilizes at a lower rate than at higher pH values. However, some ammonia volatilization occurs even under moderately acidic conditions. As pH increases above 7.0, the concentration of ammonia increases, as does the rate of ammonia volatilization. The pH of manure handled as solids can be in the range of 7.5 to 8.5, which results in fairly rapid ammonia volatilization. Manure handled as liquids or semi solids tend to have a lower pH. Nitrogen losses from animal manure as ammonia can easily exceed 50 percent (Van Horn et al., 1994).

- Nitrous oxide. Nitrous oxide also can be produced from the microbial decomposition of organic nitrogen compounds in manure. Unlike ammonia, however, nitrous oxide will be emitted only under certain conditions. Nitrous oxide emissions will occur only if nitrification occurs and is followed by denitrification. Nitrification is the microbial oxidation of ammonia to nitrites and nitrates, and the process requires an aerobic environment. Denitrification most commonly is a microbially mediated process where nitrites and nitrates are reduced under anaerobic conditions. The principal end product of denitrification is dinitrogen gas (N_2). However, small amounts of nitrous oxide as well as nitric oxide also can be generated under certain conditions. Therefore, for nitrous emissions to occur, the manure must first be handled aerobically and then anaerobically.

Research indicates that aerobic manure storage produces more nitrous oxide than anaerobic storage such as lagoons (AAF Canada, 1998). Nitrous oxide emissions are most likely to occur from unpaved drylots for dairy and beef cattle and at land application sites. These are the sites most likely to have the necessary conditions for both nitrification and denitrification. At these sites, the ammonia nitrogen that is not lost by volatilization will be adsorbed on soil particles and subsequently oxidized to nitrite and nitrate nitrogen. Emissions of nitrous oxide from these sites will depend on two primary factors. The first is drainage. In poorly drained soils, the frequency of saturated conditions, and thus the anaerobic conditions necessary for denitrification, will be higher than for well-drained soils. Conversely, the opportunity for leaching of nitrite and nitrate nitrogen through the soil will be higher in well-drained soils, and the conversion to nitrous oxide will be less. Therefore, poorly drained soils will enhance nitrous oxide emissions. The second factor is plant uptake of ammonia and nitrate nitrogen. Manure that is applied to cropland outside of the growing season will have more available nitrogen for nitrous oxide emissions as will manure that is applied at higher than agronomic rates.

- Methane. With respect to livestock emissions, methane is produced during the normal digestive processes of animals and the decomposition of animal manure. This analysis only assesses the amount of methane produced during decomposition of animal manure. Methane is a by-product of the microbial degradation of organic matter under anaerobic conditions. The microorganisms responsible, known collectively as methanogens, decompose the carbon (cellulose, sugars, proteins, fats) in manure and bedding materials into methane and carbon dioxide. Because anaerobic conditions are necessary, manure handled as a liquid or slurry will emit methane. Because methane is insoluble in water, it volatilizes from solution as rapidly as it is generated. Concurrent with the generation of methane is the microbially mediated production of carbon dioxide, which is only sparingly soluble in water. Therefore, methane emissions are accompanied by carbon dioxide emissions. The mixture of these two gases is commonly referred to as biogas. The relative fractions of methane and carbon dioxide in biogas vary depending on the population of methanogens present. Under conditions favorable for the growth of methanogens, biogas normally will be between 60 and 70 percent methane and 30 to 40 percent carbon dioxide. If, however, the growth of methanogens is inhibited, the methane fraction of biogas can be less than 30 percent.

The principal factors affecting methane emissions are the methane-producing potential of the waste and the portion of the manure that decomposes anaerobically. The second factor depends on the biodegradability of the organic fraction and how the manure is managed. The organic content of manure is measured as volatile solids. When manure is stored or handled as a liquid (e.g., anaerobic lagoons, ponds, tanks, pits), it will decompose anaerobically and produce a significant quantity of methane. Anaerobic lagoons are designed to balance methanogenic microbial activity with organic loading and, therefore, will produce more methane than ponds or tanks. When manure is handled as a solid (e.g., in open feedlots or stockpiles), it tends to decompose aerobically, and little or no methane is produced. Likewise, manure application sites are not likely sources of methane, because the necessary anaerobic conditions generally do not exist, except when soils become saturated. In addition, because methane is insoluble in water, any methane generated during liquid storage or stabilization treatment will be released immediately and will not be present when manure is applied to cropland.

- Hydrogen sulfide. Hydrogen sulfide and other reduced sulfur compounds are produced as manure decomposes anaerobically. Hydrogen sulfide is the predominant reduced sulfur compound emitted from CAFOs. Other compounds that are emitted are methyl mercaptan, dimethyl sulfide, dimethyl disulfide, and carbonyl sulfide. Small quantities of other reduced sulfur compounds are likely to be emitted as well. There are two primary sources of sulfur in animal manure: sulfur amino acids contained in the feed and inorganic sulfur compounds, such as copper sulfate and zinc sulfate, which are used as feed additives to supply trace minerals and serve as growth stimulants. Although sulfates are used as trace mineral carriers in all sectors of animal agriculture, their use is more extensive in the poultry and swine industries. A possible third source of sulfur in some locations is trace minerals in drinking water.

  Under anaerobic conditions, any excreted sulfur that is not in the form of hydrogen sulfide will be reduced microbially to hydrogen sulfide. Therefore, manure managed as liquids or slurries are potential sources of hydrogen sulfide emissions. The magnitude of hydrogen sulfide emissions is a function of liquid phase concentration, temperature, and pH. Temperature and pH affect the solubility of hydrogen sulfide in water. The solubility of hydrogen sulfide in water increases at pH values above 7. Therefore, as the pH shifts from alkaline to acidic ($pH<7$), the potential for hydrogen sulfide emissions increases. Under anaerobic conditions, livestock and poultry manure will be acidic, with pH values ranging from 5.5 to 6.5. Under aerobic conditions, any reduced sulfur compounds in manure will be oxidized microbially to nonvolatile sulfate, and emissions of hydrogen sulfide will be minimal. Therefore, emissions from confinement facilities with dry manure handling systems and dry manure stockpiles should be negligible if there is adequate exposure to atmospheric oxygen to maintain aerobic conditions. Any hydrogen sulfide that is generated in dry manure generally will be oxidized as diffusion through aerobic areas occurs.

- Criteria air pollutants. CAFOs that transport their manure off site and/or compost their manure on site use equipment (e.g., trucks, tractors) that release criteria air pollutants when operated. Criteria air pollutants are also released when biogas, generated from energy recovery systems or anaerobic digesters, is used for fuel (e.g., in an engine or flared). The criteria air pollutants included in this analysis are volatile organic compounds (VOCs), nitrogen oxides (NO_x), particulate matter (PM), and carbon monoxide (CO). Sulfur dioxide (SO_2) is also estimated for energy recovery systems, as it is a byproduct of the flaring and combustion process.

- Energy usage. CAFOs also use energy when transporting manure off site, applying manure to land, and performing on-site operations such as composting. In some cases, the CAFO may generate energy from capturing and using biogas. Energy usage included in this analysis are kilowatt hours (kW-hr) and fuel (gallons).

Animal feeding operations generate air emissions and use energy in their operations under baseline conditions (i.e., prior to implementation of a regulatory option). Where possible, the NWQI estimates include baseline estimates, as well as estimates for each regulatory option. In some cases, however, there are insufficient data to quantify baseline NWQI. In these cases, the impacts presented in this report reflect only the expected change in impacts due to implementation of the regulatory options. Table 1.1-1 summarizes the air pollutant emissions and energy usage expected from each of the production system components.

Table 1.1-1

Air Pollutant Emissions and Energy Usage Considered, by Production System Component

Pollutant/ Energy usage	Drylot	Storage	Stockpile[a]	Land application[b]	Manure hauling/ Transport	Biogas burning
Ammonia (NH_3)	√	√	√	√		
Nitrous oxide (N_2O)	√	√	√	√		
Methane (CH_4)	√	√	√			
Hydrogen sulfide (H_2S)	√	√	√			
Volatile Organic Compounds (VOCs)			√		√	
Nitrogen Oxides (NOx)			√		√	√
Particulate matter (PM)			√		√	
Carbon monoxide (CO)			√		√	√
Sulfur dioxide (SO_2)					√	√
Energy usage (kW-hrs)				√		√
Fuel (gallons)			√	√	√	

[a]Includes composting activities, which require the use of diesel-powered equipment.
[b]Includes the use of irrigation equipment to apply liquid manure.

1.2 Overview of Regulatory Options

Non-water quality impacts are presented in this report for the following seven regulatory options for CAFOs considered by EPA. These options are:

1. Zero discharge from a facility designed, maintained, and operated to hold the waste and wastewater, including stormwater, from runoff plus the 25-year, 24-hour storm event. This option includes implementation of feedlot best management practices, including stormwater diversions, lagoon and pond depth markers, periodic inspections, nitrogen-based agronomic application rates, elimination of manure application within 100 feet of any surface water, tile drain inlet, or sinkhole, and mortality-handling, nutrient management planning, and record-keeping guidelines.

2. The same as Option 1, except nitrogen-based agronomic application rates are replaced by phosphorus-based agronomic application rates as dictated by site-specific conditions.

3. The same as Option 2, plus additional groundwater conditions.

4. The same as Option 2, plus additional surface water monitoring.

5. For swine, poultry, and veal operations, the same as Option 2, but is based on zero discharge with no overflow under any circumstances (i.e., total confinement and covered storage).

5A. For beef feedlots, dairies, and heifer operations, the same as Option 2, plus implementation of a drier manure management system (i.e., composting).

6. For Large swine operations and dairies, the same as Option 2, plus implementation of anaerobic digestion with energy recovery.

7. The same as Option 2, plus timing restrictions on land application of animal waste to frozen, snow-covered, or saturated ground.

EPA developed these regulatory options to ensure the protection of surface water in and around CAFOs; however, one or more of the requirements included in these options may also have an impact on the amount and form of compounds released to air, as well as the energy that is required to operate the CAFO.

1.3 <u>Overview of Model Farm Operations</u>

EPA develops NWQI estimates first at the model-farm level for each regulatory option. These estimates then can be aggregated to estimate industry-level NWQI. To this end, EPA estimates the compliance costs (i.e., the cost to comply with the option) and non-water quality impacts (i.e., the impact the option has on the release of constituents to media other than water) incurred through the implementation of each option. To accomplish this task, EPA initially defines the baseline conditions that are present in the industry (i.e., prior to implementing any new requirements, EPA defines how the industry currently operates).

When farm-specific data are not available, EPA develops model farms to provide a reasonable representation of the industry. The Agency develops model farms to reflect the different characteristics found in the industry, such as the size or capacity of an operation, type of operation, geographic location, mode of operation, and type of waste management operations.

These models are based on data gathered during site visits, information provided by industry members and their associations, and other available information. EPA estimates the number of facilities that are represented by each model, estimates the impacts for each model farm, and then calculates industry-level impacts by multiplying model farm estimates by the number of facilities represented by each particular model. Given the amount and type of information that is available for the CAFOs, EPA has chosen a model-farm approach to estimate NWQI and to define baseline conditions.

Model farms are based on the size of the operation, regional location, and/or waste management practices. For this analysis, EPA modeled Medium and Large CAFOs throughout the United States. Large AFOs are considered CAFOs if they fall within the size range presented in Table 1.3-1. Medium AFOs are defined as CAFOs only if they fall within the size range presented in Table 1.3-1 and they meet one of the two specific criteria governing the method of discharge: (1) pollutants are discharged through a man-made ditch, flushing system, or other similar man-made device; or (2) pollutants are discharged directly into waters of the United States that originate outside the facility and pass over, across, or through the facility or otherwise come into direct contact with the confined animals.

Table 1.3-1

Summary of Size Thresholds for Large and Medium CAFOs

Sector	Large	Medium[a]
Mature dairy cattle	More than 700	200 - 700
Veal calves	More than 1,000	300 - 1,000
Cattle or cow/calf pairs	More than 1,000	300 - 1,000
Swine (weighing 55 pounds or more)	More than 2,500	750 - 2,500
Swine (weighing less than 55 pounds)	More than 10,000	3,000 - 10,000
Turkeys	More than 55,000	16,500 - 55,000
Chickens (liquid manure handling system)	More than 30,000	9,000 - 30,000
Chickens other than laying hens (other than a liquid manure handling system)	More than 125,000	30,000 - 125,000
Laying hens (other than a liquid manure handling system)	More than 82,000	25,000 - 82,000

[a] Must also meet one of two criteria to be defined as a CAFO.

More specifically, EPA developed and analyzed up to five size groups for each animal type, including one to two size groups covering large CAFOs and three size groups covering Medium CAFOs. The size groups were analyzed to evaluate the costs, benefits, and impacts of each potential regulatory option. Table 1.3-2 presents the size groups for each animal type.

Table 1.3-2

Size Classes for Model Farms

Animal Type	Medium 1	Medium 2	Medium 3	Large 1	Large 2
Beef	300-499	500-749	750-999	1,000-7,999	≥8,000
Heifer	300-499	500-749	750-999	≥1,000	N/A
Dairy (Mature Dairy Cows)	200-349	350-524	525-699	≥700	N/A
Veal	300-499	500-749	≥750	N/A	N/A
Swine	750-1,249	1,250-1,874	1,875-2,499	2,500-4,999	≥5,000
Dry Layers	25,000-49,999	50,000-74,999	75,000-81,999	82,000-599,999	>600,000
Wet Layers	N/A	N/A	9,000-29,999	>30,000	N/A
Broilers	37,750-49,999	50,000-74,999	75,000-124,999	125,000-179,999	≥180,000
Turkeys	16,500-27,499	27,500-41,249	41,250-54,999	≥55,000	N/A

N/A - Not applicable.

In addition, the farms are broken out into five different geographic locations throughout the United States. These regions are:

- Central: AZ, CO, ID, MT, NM, NV, OK, TX, UT, WY;
- Mid-Atlantic: CT, DE, KY, MA, MD, ME, NC, NH, NJ, NY, PA, RI, TN, VA, VT, WV;
- Midwest: IA, IL, IN, KS, MI, MN, MO, ND, NE, OH, SD, WI;
- Pacific: AK, CA, HI, OR, WA; and
- South: AL, AR, FL, GA, LA, MS, SC.

The following subsections summarize the method(s) of operation for each model farm, the size of the operation for each model, and the industry population that makes up the model farm (by geographic region). Additional data on the model farms, including the determination of model farm populations, data on waste generation, and sources used can be found in the cost methodology report summarizing EPA's compliance cost estimates (U.S. EPA, 2002a).

1.3.1 Beef Feedlots and Heifer Operations

Beef feedlots and heifer operations house cattle on drylots. The manure that deposits in the drylot is periodically scraped and stockpiled on site or transported to cropland on or off site. It is handled as a solid material. Runoff from the operation is typically collected and stored in a waste storage pond, which is sometimes preceded by a sedimentation basin. Figure 1.3-1 depicts the waste management system for the model beef feedlot and heifer operation.

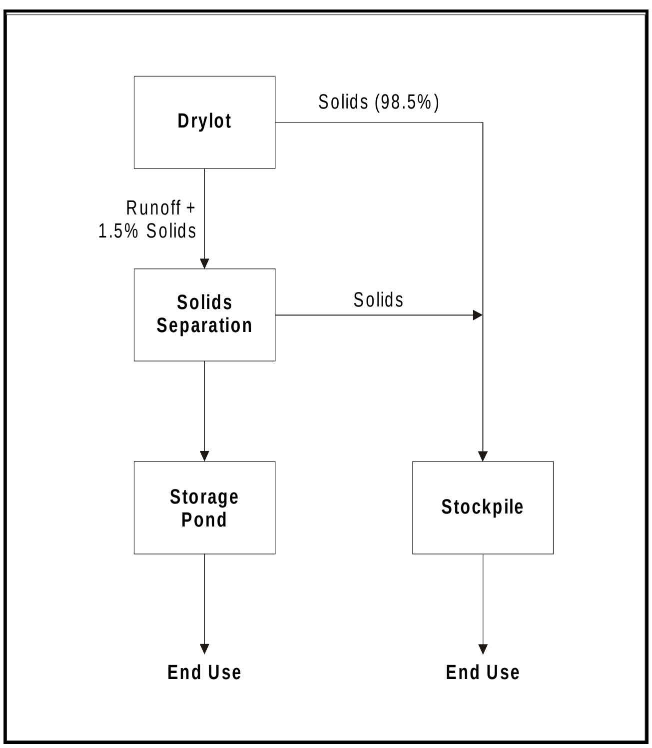

Figure 1.3-1. Waste Management at the Model Beef Feedlot and Heifer Operation

Table 1.3-3 presents the estimated number of beef feedlots and heifer operations by model farm in each region.

Table 1.3-3

Number of Beef Feedlots and Heifer Operations by Size and Region

Animal Type	Size Class	Average Head	Region					Total
			Central	Mid-Atlantic	Midwest	Pacific	South	
Beef	Large 2	25,897	133	3	268	17	N/A	421
	Large 1	1,839	424	8	856	57	N/A	1,345
	Medium 3	766	6	0.4	20	1	0.1	28
	Medium 2	552	9	1	40	1	0.2	52
	Medium 1	370	17	2	73	2	0.3	94
Heifer	Large 1	1,500	145	N/A	N/A	97	N/A	242
	Medium 3	875	9	N/A	8	3	N/A	20
	Medium 2	625	22	N/A	20	7	N/A	48
	Medium 1	400	8	N/A	150	4	N/A	162

1.3.2 Dairies

Two types of waste management systems are modeled for dairies: flush dairies (e.g., flush both barn and milking parlor) and scrape/hose dairies (e.g., scrape barn and hose milking parlor).

Dairies with flush barns house the milking cows (both lactating and dry) in freestall barns that are flushed two to three times daily while the cows are being milked. The cows are milked in separate parlors that are also flushed in between milkings. Flush water is collected in a central collection system and transported to an on-site anaerobic lagoon, which in some cases may be preceded by solids separation. Immature animals (i.e., heifers and calves) are housed on drylots. The manure that deposits in the drylot is handled as a solid material and is periodically scraped and stockpiled on site or transported to cropland on or off site. Runoff from the drylot is routed to the lagoon. Figure 1.3-2 depicts the waste management system for the flush dairy model farm.

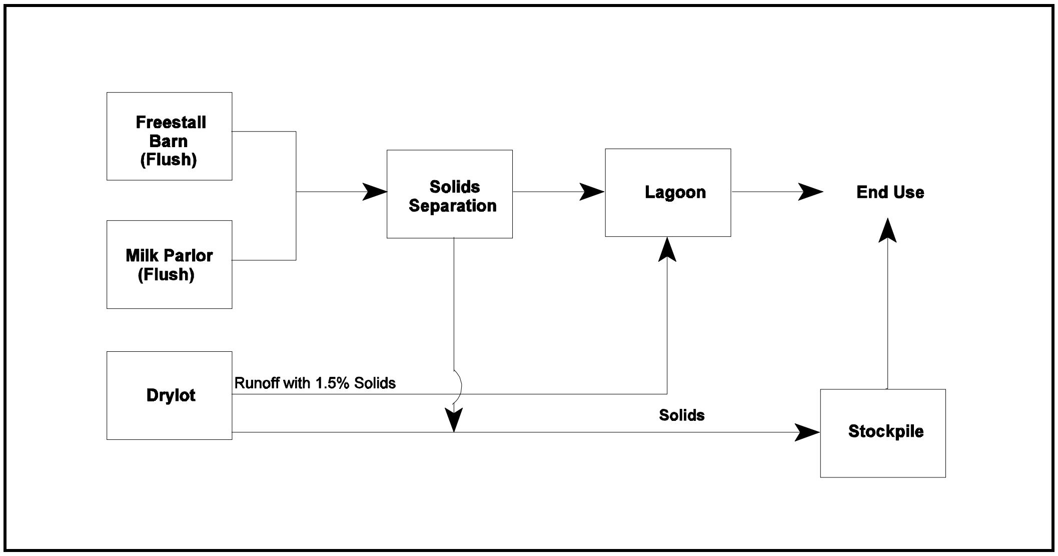

Figure 1.3-2. Waste Management at the Flush Dairy Model Farm

Dairies with scrape barns house the milking cows (both lactating and dry) in freestall barns that are scraped daily. The scraped manure is stockpiled on site or transported to cropland on or off site. The cows are milked in separate parlors that are hosed down between milkings. Parlor hose water is collected in a central collection system and transported to an on-site anaerobic lagoon, which in some cases may be preceded by solids separation. Immature animals (i.e., heifers and calves) are housed on drylots. The manure that deposits in the drylot is handled as a solid material and periodically scraped and stockpiled on site or transported to cropland on or off site. Runoff from the drylot is routed to the lagoon. Figure 1.3-3 depicts the waste management system for the scrape/hose dairy model farm.

The facility includes all contiguous and non-contiguous property with established boundaries owned, operated, leased, or under control of the business entity. The property may be divided by public or private right-of-way.

Table 1.3-4 presents the estimated number of dairies by model farm in each region.

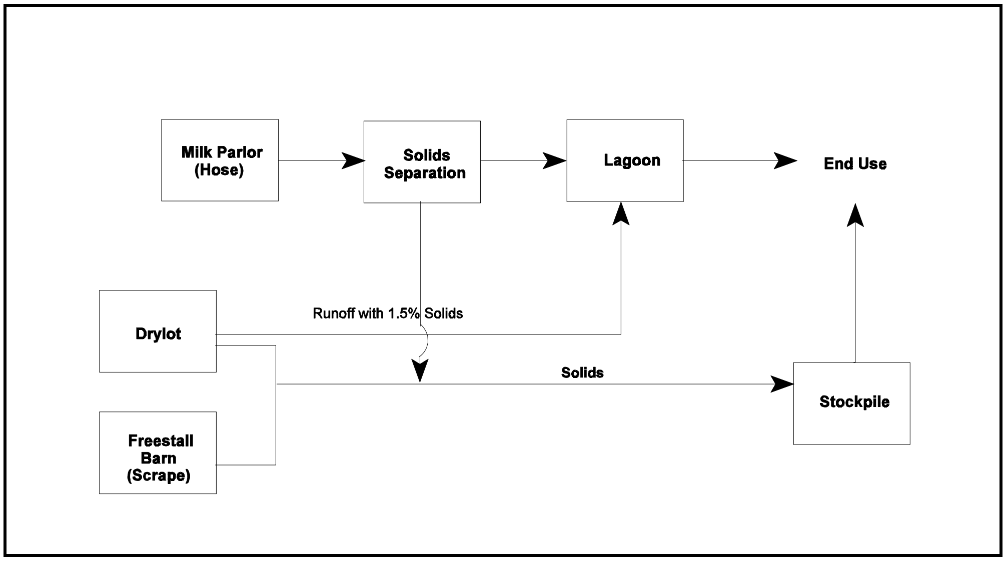

Figure 1.3-3. Waste Management at the Scrape/Hose Dairy Model Farm

Table 1.3-4

Number of Dairies by Size and Region

Animal Type	Size Class	Average Head	Region					Total
			Central	Mid-Atlantic	Midwest	Pacific	South	
Dairy	Large 1	1,430	401	104	95	759	91	1,450
	Medium 3	600	25	41	26	30	15	138
	Medium 2	425	48	194	172	29	36	480
	Medium 1	250	133	538	478	81	100	1,331

1.3.3 Veal Operations

Veal calves are housed in total confinement barns. Two types of waste management systems are modeled for veal operations: deep pit storage system and flush system. In both systems, the floor of the barn is composed of slats directly above a storage pit (deep pit storage system) or flush alley (flush system).

Veal operations with flush systems wash the storage pits with a large volume of water once a day or more to remove the waste from the pit. The waste is washed into a lagoon where it is stored until it is land applied or transported off site. The model farm assumes that 67 percent of the veal industry uses the flush system. Figure 1.3-4 depicts the waste management system for the veal flush system model farm.

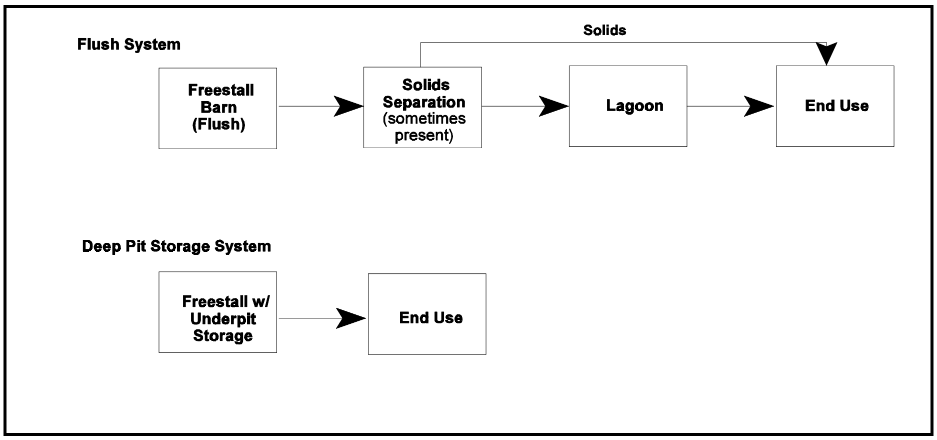

Figure 1.3-4. Waste Management at the Veal Model Farm

Veal operations with deep pit systems start with several inches of water in the pit under the house, where the manure is stored until it is pumped out for field application approximately twice a year. This system uses less water, creating a slurry that has higher nutrient concentrations than the liquid manure systems. The model farm assumes that 33 percent of the veal industry uses the deep pit system. Figure 1.3-4 depicts the waste management system for the veal deep pit system model farm.

Table 1.3-5 presents the estimated number of veal operations by model farm in each region.

Table 1.3-5

Number of Veal Operations by Size and Region

Animal Type	Size Class	Average Head	Region					Total
			Central	Mid-Atlantic	Midwest	Pacific	South	
Veal	Medium 3	1,080	1	N/A	16	N/A	N/A	17
	Medium 2	540	0.1	0.0	1	N/A	N/A	1
	Medium 1	400	0.1	0.0	2	N/A	N/A	2

1.3.4 Swine Operations

Swine are housed in total confinement barns. Two types of waste management systems are modeled for swine operations: deep pit storage system and flush system. In both systems, the floor of the barn is composed of slats directly above a storage pit (deep pit storage system) or flush alley (flush system).

Swine operations with flush systems wash the storage pits with a large volume of water once a day or more to remove the waste from the pit. The waste is washed into a lagoon where it is stored until it is land applied or transported off site. Figure 1.3-5 depicts the waste management system for the swine flush system model farm. Operations in the Central region are assumed to operate an evaporative lagoon, while operations in the Mid-Atlantic and Midwest are assumed to operate a traditional anaerobic lagoon.

Swine operations with deep pit systems start with several inches of water in the pit under the house, where the manure is stored until it is pumped out for field application approximately twice a year. This system uses less water, creating a slurry that has higher nutrient concentrations than the liquid manure systems. Figure 1.3-5 depicts the waste management system for the swine deep pit system model farm.

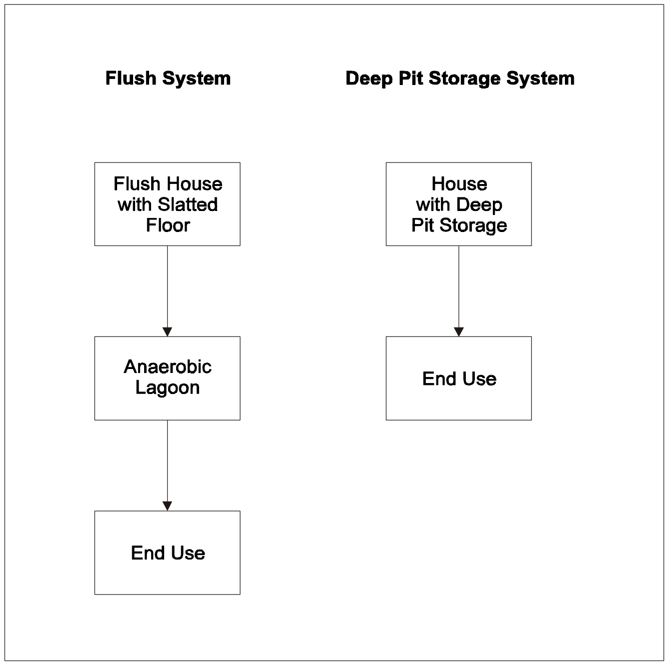

Figure 1.3-5. Waste Management at the Swine Model Farm

The waste produced at an operation is dependent of the type of animals that are present. In farrow-to-finish (FF) operations, the pigs are born and raised at the same facility. In grow-finish (GF) operations, young pigs are first born and cared for at a nursery and then brought to the finishing farm.

Table 1.3-6 presents the estimated number of swine operations by model farm in each region.[1]

[1]Because swine are managed indoors, climate is not a major factor in determining farm characteristics; therefore, only three regions (rather than five as with beef, heifer and dairy) are modeled for these animal groups. Although the number of swine operations are reported in Table 1.3-6 only for the Central, Mid-Atlantic, and Midwest regions, the facility count actually represents all farms in the United States.

Table 1.3-6

Number of Swine Operations by Size and Region

Animal Type	Size Class	Region					
		Central		Mid-Atlantic		Midwest	
		Average Head	Number of Facilities	Average Head	Number of Facilities	Average Head	Number of Facilities
Swine (FF)	Large 2	8,298	105	17,118	288	13,819	609
	Large 1	3,626	126	3,509	218	3,444	992
	Medium 3	N/A	N/A	2,165	18	2,152	118
	Medium 2	N/A	N/A	1,518	30	1,460	266
	Medium 1	N/A	N/A	846	59	814	521
Swine (GF)	Large 2	29,389	55	8,893	386	10,029	196
	Large 1	3,455	85	3,554	387	3,417	477
	Medium 3	N/A	N/A	2,184	25	2,124	64
	Medium 2	N/A	N/A	1,521	19	1,422	110
	Medium 1	N/A	N/A	963	37	900	215

N/A - There are no Medium swine operations in the Central Region.

1.3.5 Poultry Operations

Model farms for broiler, turkey, dry layer, and wet layer operations are developed to represent poultry operations in the United States.

Broilers and turkeys are typically housed in long barns (approximately 40 feet wide and 400 to 500 feet long) and are grown on the floor of the house. A layer of bedding (e.g., wood shavings) is added to the floor of the barn, and the broilers or turkeys deposit manure directly onto the bedding. Bedding is initially added to the houses at a depth of approximately four inches and about one inch of new bedding is applied between flocks.

Manure from broiler and turkey operations accumulates on the floor where it is mixed with bedding, forming litter. Litter close to drinking water forms a cake that is removed between flocks. The rest of the litter in a broiler house is removed periodically (6 months to 2 years) from the barns, and then transported off site or land applied. Typically, broiler and turkey operations are completely dry waste management systems. Figure 1.3-6 presents the waste management system for both the broiler and turkey model farm.

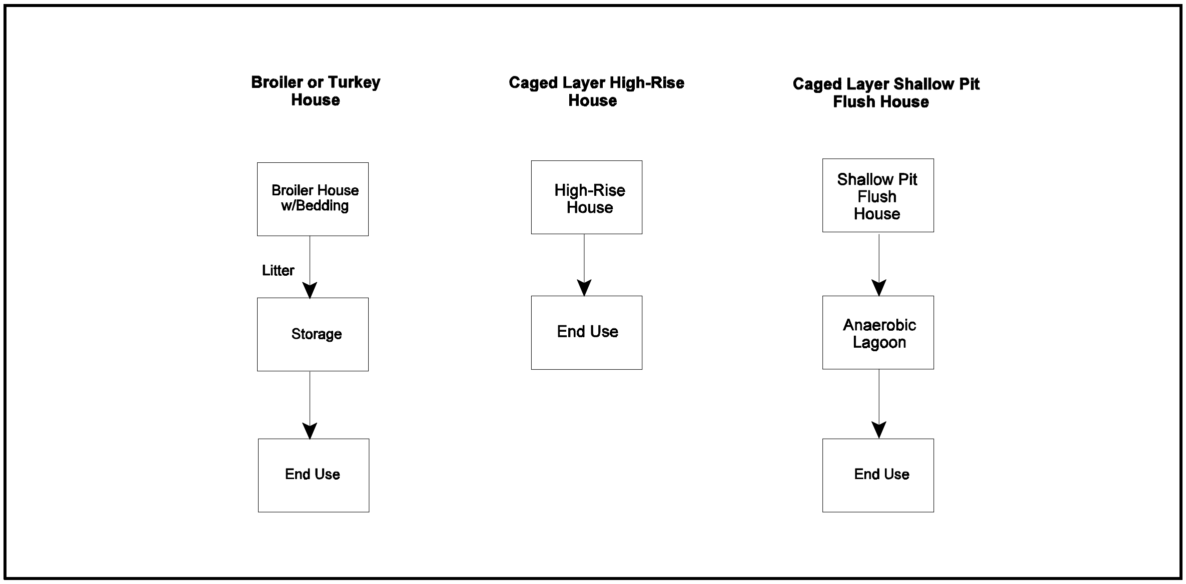

Figure 1.3-6. Waste Management at Poultry Model Farms

Layers are typically confined in cages that are housed in high-rise cage systems or shallow pit flush housing. In a high-rise house, the layer cages are suspended over a bottom story, where the manure is deposited and stored. Housing facilities for flush cage systems are typically one story. The tiered cages are suspended over a shallow pit. Manure drops directly into the pit, where it is flushed out periodically using recycled lagoon water.

Layer operations may operate as a wet or a dry system. Approximately 10 percent of layer houses use liquid flush, where waste is removed from the house and stored in a lagoon. The remaining layer operations typically operate as a dry system, with manure stored in the house for up to a year. A scraper is used to remove waste from the collection pit or cage area. The lagoon wastewater and dry manure are stored until land applied or transported off site. Figure 1.3-6 presents the waste management system for the wet and dry layer model farm.

Table 1.3-7 presents the estimated number of poultry operations by model farm in each region.[2]

Table 1.3-7

Number of Poultry Operations by Size and Region

Animal Type	Size Class	Regions					
		Mid-Atlantic		Midwest		South	
		Average Head	Number of Facilities	Average Head	Number of Facilities	Average Head	Number of Facilities
Broiler	Large 2	373633	174	N/A	N/A	376099	424
	Large 1	119756	338	N/A	N/A	118624	696
	Medium 3	80756	61	N/A	N/A	80978	124
	Medium 2	51603	70	N/A	N/A	51380	127
	Medium 1	39218	53	N/A	N/A	39046	85
Layer - Dry	Large 2	N/A	N/A	1229095	61	884291	26
	Large 1	N/A	N/A	232259	439	244163	198
	Medium 3	N/A	N/A	84731	0.7	84669	0.5
	Medium 2	N/A	N/A	52582	4	44909	3
	Medium 1	N/A	N/A	35781	7	30560	8
Layer - Wet	Large 1	N/A	N/A	N/A	N/A	86898	383
	Medium 3	N/A	N/A	N/A	N/A	3654	24
Turkey	Large 1	97111	163	158365	225	N/A	N/A
	Medium 3	45193	3	45469	2	N/A	N/A
	Medium 2	31267	5	30514	4	N/A	N/A
	Medium 1	18539	9	18092	8	N/A	N/A

N/A - Not applicable.

[2]Because poultry are managed indoors, climate is not a major factor in determining farm characteristics; therefore, only one or two regions (rather than five as with beef, heifer, dairy, and veal) are modeled for these animal groups. Although the number of poultry operations are reported in Table 1.3-7 only for certain regions, the facility count actually represents all farms in the United States. The regions presented in the table are those where the majority of the operations are located.

1.4 Changes to Calculation Methodology Since Proposal

Five major changes occurred since proposal that affect the industry scope and the definition of the model farms. These changes, presented below, greatly affect the magnitude of the non-water quality impact estimates.

- Industry Threshold. At proposal, EPA calculated industry-level non-water quality impacts for the two regulatory thresholds proposed for the NPDES program. Threshold 1 is a two-tier structure that establishes a single threshold at the equivalent of 500 AU; therefore, EPA included all operations defined as having 500 AU or more in the Threshold 1 estimates. Threshold 2 is a three-tier structure that defines all operations with 1,000 AU or more as CAFOs, but only a subset of operations with 300 to 1,000 AU as CAFOs. The final non-water quality impacts estimates are presented for all Medium and Large CAFOs.

- Facility Counts. The number of facilities, broken out by region and size group, have changed since proposal based on new data provided by USDA. In some cases, the number of facilities has greatly increased.

- Average Head. Due in part to new data provided by USDA, the average head by size group has changed since proposal. The average head counts used at proposal for broiler, turkeys, dry layers, and swine varied by region, while the new head counts provided by USDA do not.

- New Size Group. Since proposal, the Medium 2 size group has been broken into two groups: Medium 2 and Medium 3.

- High/Medium/Low Performers. Based on data provided by USDA, certain model farms were broken into high, medium, and low performers for certain waste management components (i.e., concrete and earthen settling basins, liquid land application, and berms). This change impacts the number of operations with these waste management components at baseline.

In addition, EPA has made several changes to the methodologies for estimating the NWQI. These changes were based upon both internal reviews and updates supported by ongoing scientific research reported in the literature, as well as technical review comments provided by EPA's Office of Air and Radiation.

- Ammonia and Hydrogen Sulfide. The methodology for calculating ammonia and hydrogen sulfide emissions from CAFOs include revised emission factors for estimating emissions from lagoons and ponds, swine deep pits, and manure composting.

- Greenhouse Gases. EPA made changes to the methodologies for calculating greenhouse gas emissions from CAFOs, including the removal of carbon dioxide emissions from the analysis, a revised nitrous oxide emission factor for poultry housing without bedding, an updated methane conversion factor methodology for liquid systems, and the inclusion of nitrous oxide emissions from land application activities.

- Emissions from Transportation of Manure. EPA also made changes to the methodologies for estimating air emissions from the transport of excess manure. In the revised transportation emission estimates, EPA included transportation emissions from phosphorous-based Category 3 facilities, assumed that liquid manure is applied before solid manure, and used revised transportation emission factors for volatile organic compounds, nitrogen oxides, and carbon monoxide.

- Energy Recovery Systems. EPA made changes to the methodology and scope for the estimation of air emissions and energy savings from the operation of energy recovery systems under Option 6. Theses changes include revising the swine model farms, including the use of anaerobic digesters for Large 1 swine operations under Option 6, and deleting the air emissions estimates associated with energy recovery systems.

- Boundary Conditions of Analysis. EPA also expanded the land application losses for both ammonia and nitrous oxide to include both on- and off-site land application activities, and added an estimation of fuel usage to the energy impacts.

1.5 Structure of Report

This report presents estimates of NWQI at Large and Medium CAFOs. Each section discusses the methodology used to estimate the impacts and presents example calculations. Estimates of NWQI are developed for each model farm considered by EPA. The emissions for each pollutant are calculated on either a 1,000-pound animal weight basis, or on a per-head basis. These emissions are converted to model farm estimates by multiplying by the number of animals present at the model farm (and their weight, if necessary), as shown in the following equation:

$$\text{Emissions}_{\text{annual}} = \text{Emissions}_{\text{animal}} \times \text{Number of head} \times \text{Animal weight}$$

where:

$\text{Emissions}_{\text{annual}}$	=	Annual pollutant emissions (lb/yr) at the model farm
$\text{Emissions}_{\text{animal}}$	=	Annual emissions per 1,000-pound animal (lb/yr/1,000 lb) or per head
Number of head	=	Number of head at the model farm
Animal Weight	=	Average weight of each animal (lb/head).

Industry-level NWQI for each animal sector (i.e., beef, dairy, veal, swine, and poultry) are estimated for Large and Medium CAFOs. The industry-level impacts are calculated by multiplying the model farm impacts by the number of facilities represented by that model farm. Section 6 presents these industry-level estimates.

The remainder of this report contains the following information:

- Section 2.0 discusses the methodology and model farm results for air emissions from the animal production area;
- Section 3.0 discusses the methodology and model farm results for air emissions from the application of manure to land;
- Section 4.0 discusses the methodology and model farm results for air emissions from vehicles;

- Section 5.0 discusses the methodology and model farm results for energy impacts;

- Section 6.0 summarizes the industry-wide non-water quality impacts for two regulatory thresholds considered by EPA; and

- Section 7.0 provides a list of references used throughout this report.

The following appendices are also included:

- Appendix A - Emission Factor Derivation and Detailed Calculations for Air Emissions from Animal Confinement and Manure Management Systems - Ammonia and Hydrogen Sulfide Emissions;

- Appendix B - Detailed Calculations for Air Emissions from Animal Confinement and Manure Management Systems - Greenhouse Gas Emissions;

- Appendix C - Detailed Calculations for Air Emissions from Animal Confinement and Manure Management Systems - Energy Recovery Systems;

- Appendix D - Detailed Calculations for Air Emissions - Land Application Activities;

- Appendix E - Detailed Calculations for Emissions from Vehicles Used for Off-Site Transportation;

- Appendix F - Detailed Calculations for Emissions from Vehicles Used for Composting;

- Appendix G - Detailed Calculations for Energy Impacts - Land Application; and

- Appendix H - Detailed Calculations for Energy Impacts - Anaerobic Digesters with Methane Recovery.

2.0 AIR EMISSIONS FROM ANIMAL CONFINEMENT OPERATIONS

Animal feeding operations generate various types of animal wastes, including manure (feces and urine), waste feed, water, bedding, dust, and wastewater. As these wastes decompose, they generate air emissions, from the time they are generated through their management and treatment on site. The rate of emission generation varies based on operational variables (e.g., animal species, type of housing, waste management system) and weather conditions (e.g., temperature, humidity, wind, time of release).

ERG evaluated air releases occurring from animal confinement areas and manure management systems for animal feeding operations for baseline conditions and seven regulatory options. Limited data exist on these releases to allow a complete analysis of all possible compounds; therefore, ERG focused on the release of ammonia, hydrogen sulfide, and greenhouse gases (methane and nitrous oxide) from animal confinement and waste management systems and certain criteria air pollutants (carbon monoxide, nitrogen oxides, volatile organic compounds, and particulate matter) from energy recovery systems.

This section presents the methodology and model farm results for the following air emission calculations from animal confinement operations:

- Section 2.1 - Ammonia and hydrogen sulfide from animal confinement and waste management systems;
- Section 2.2 - Greenhouse gases from animal confinement and waste management systems; and
- Section 2.3 - Criteria air pollutants from energy recovery systems.

2.1 <u>Ammonia and Hydrogen Sulfide Emissions from Animal Confinement and Manure Management Systems</u>

Animal housing and manure management systems produce ammonia (NH_3) and hydrogen sulfide (H_2S) emissions. This subsection presents the data inputs and the calculation methodology used to estimate ammonia and hydrogen sulfide emissions from confinement areas and manure management systems as well as a summary of the model farm results. Appendix A presents example calculations.

2.1.1 Data Inputs

To estimate ammonia and hydrogen sulfide emissions from confinement areas and manure management systems ERG used a number of data inputs, including:

- Animal weight;
- Nitrogen excretion rate; and
- Sulfur excretion rate.

Table 2.1-1 presents the waste characteristics data used in the ammonia and hydrogen sulfide emission calculations for each of the animal types modeled. ERG obtained nitrogen and sulfur excretion rate data from the Agricultural Waste Management Field Handbook (USDA, 1996).

Table 2.1-1

Data Inputs for Calculating Emissions from Confinement Housing

Parameter	Value by Animal Type							
	Beef	Heifer	Veal	Dairy	Swine	Broilers	Layers	Turkeys
Animal Weight (lbs)	877	550	350	Mature 1,350 Heifer 550 Calf 350	135	2.0	4.0	15.0
Nitrogen as excreted (lb/day/1000 lb animal)	0.34	0.31	0.2	Mature 0.45 Heifer 0.31 Calf 0.27	0.42	1.1	0.79	0.74
Sulfur as excreted (lb/day/1000 lb animal)	NA	NA	0.051	0.051	0.076	NA	NA	NA

NA - Not Applicable.

Information on the quantity of nitrogen lost from the animal confinement areas and manure management systems is also needed to calculate ammonia emissions. The amount of nitrogen present in the runoff from drylots is calculated in the model used to estimate compliance costs for each regulatory option and documented in the Cost Methodology Report (U.S. EPA, 2002a). It is assumed that the solid concentration in the runoff is 1.5 percent (MWPS, 1987) and that the concentration of each constituent is that of manure. Table 2.1-2 presents the nitrogen expected to be lost in runoff from beef feedlots, heifer operations, and dairies.

Table 2.1-2

Nitrogen Runoff Losses from Beef, Heifer, and Dairy Drylots by Region

	Nitrogen Runoff Losses (lb/yr/head)				
Animal Type	**Central**	**Mid-Atlantic**	**Midwest**	**Pacific**	**South**
Beef	7.64	24.71	12.86	26.69	29.38
Heifer	6.07	19.64	10.22	21.22	23.36
Dairy	3.69	11.93	6.21	12.89	14.19

2.1.2 Emissions Methodology

Basic ammonia and hydrogen sulfide emissions are calculated using Equation 2-1:

$$\text{Emissions (lbs per head)} = \text{Manure}_{\text{excreted}} \times \text{CF} \times \text{EF} \qquad [2\text{-}1]$$

where:

$\text{Manure}_{\text{Excreted}}$ = Nitrogen or sulfur excreted (lb/yr/head)
CF = Conversion factor (17/14 for converting N to NH_3 and 17/16 for converting S to H_2S)
EF = Emission factor (percentage).

This subsection presents the calculation methodologies used to estimate ammonia and/or hydrogen sulfide emissions from drylots, confinement houses, ponds and lagoons, stockpiles, and composted manure. This subsection also presents the emission factors used in the calculations, the derivation of the emission factors, as well as any assumptions made concerning the practices used at the animal operations.

Drylot Emissions

Drylots are used at beef feedlots, heifer operations, and dairies. All animals at beef feedlots and heifer operations spend 100 percent of their time on drylots. At dairies, the immature heifers and calves spend all of their time on drylots while the mature dairy cows spend their time in the freestall barn and milking parlor. Nitrogen is present in the excreted manure and is lost as ammonia through emissions to the air and through runoff from the drylot; no hydrogen sulfide is emitted at the drylots. The drylot ammonia emission rate is estimated based on a nitrogen emission factor and the amount of nitrogen in the manure excreted at the drylot. Some of the nitrogen in the manure excreted at the drylot, however, is removed with the drylot runoff. Equation 2-2 is used to determine the final amount of manure nitrogen at the drylot capable of contributing to ammonia emissions.

$$\text{Manure Nitrogen}_{drylot}\ (\text{lb/day/head}) = [(\text{Weight}_{heifer} \times \text{N Excreted}_{heifer}) + (\text{Weight}_{calf} \times \text{N Excreted}_{calf})] - \text{Runoff}_{nitrogen} \qquad [2\text{-}2]$$

where:

Weight_{heifer}	=	Average live weight for heifers (lb/head)
$\text{N Excreted}_{heifer}$	=	Nitrogen excretion rate for heifers (lb/day)
Weight_{calf}	=	Average live weight for calves (lb/head)
N Excreted_{calf}	=	Nitrogen excretion rate for calves (lb/day)
$\text{Runoff}_{nitrogen}$	=	Amount of nitrogen in the runoff from the drylot (lb/day/head).

Based on data collected by North Carolina State University (NCCES, 1994a, Tables 6 and 8), 45 percent of the nitrogen content of beef and heifer waste is lost from the point of generation to the point that it is scraped from unpaved lots. See Appendix A for more information on the derivation of the emission factor. The drylot ammonia emission rate is calculated using Equation 2-3.

$$\text{Ammonia Drylot Emission Rate (lb/yr/head)} = \text{Manure Nitrogen}_{drylot} \times EF \times \frac{17\ NH_3}{14\ N} \times \frac{365\ \text{days}}{\text{year}} \quad [2\text{-}3]$$

Table 2.1-3 presents the total ammonia emission rates calculated for beef, heifer, and dairy drylots by region. The emission rates vary by region, as the amount of nitrogen expected in runoff varies by region. Because none of the regulatory options affect the management of waste in the housing areas for cattle, no difference in the ammonia emissions is expected due to the regulatory options (i.e., baseline emissions equal regulatory option emissions).

Table 2.1-3

Total Ammonia Emission Rates for Beef, Heifer and Dairy Drylots by Region

Animal Type	Drylot Ammonia Emission Rates (lb/yr/head)				
	Central	Mid-Atlantic	Midwest	Pacific	South
Beef	50.20	29.47	43.86	27.06	23.79
Heifer	26.64	10.16	21.59	8.24	5.64
Dairy	11.38	1.37	8.32	0.20	0.20

Confinement House Emissions

ERG modeled a number of different confinement houses in this analysis to accommodate the different animal types and different waste management methods. Ammonia and hydrogen sulfide emissions from confinement houses are calculated using Equation 2-1 when the emission factors represent a percentage:

$$\text{Ammonia Housing Emission Rate (lb/yr/head)} = \text{Manure Nitrogen}_{excreted} \times EF \times \frac{17\ NH_3}{14\ N}$$

$$\text{Hydrogen Sulfide Housing Emission Rate (lb/yr/head)} = \text{Manure Sulfur}_{\text{excreted}} \times \text{EF} \times \frac{17\ H_2S}{16\ S}$$

where:

Manure $\text{Nitrogen}_{\text{excreted}}$	=	Nitrogen excreted in manure (lb/yr/head)
Manure $\text{Sulfur}_{\text{excreted}}$	=	Sulfur excreted in manure (lb/yr/head)
EF	=	Emission factor (percentage).

When an emission factor represents an emissions rate in lb/yr/head, that factor is used as the emission rate for that animal type. Table 2.1-4 presents the emission factors used to calculate ammonia and hydrogen sulfide emissions from confinement houses. Hydrogen sulfide is produced by the anaerobic decomposition of manure. Therefore, hydrogen sulfide emissions are only calculated for confinement houses with deep-pit systems, as these are the only houses expected to have anaerobic conditions.

Table 2.1-4

Ammonia and Hydrogen Sulfide Emission Factors for Animal Confinement Houses by Animal Type

Animal Type	Operation Type	Ammonia Emission Factor (lb/yr/head)	Hydrogen Sulfide Emission Factor (lb/yr/head)
Dairy	Flush Barn	40.97	NC
	Scrape Barn	31.43	NC
Veal	House with Lagoon System	5.55	NC
	House with Deep-Pit System	11.08	0.77
Swine	House with Lagoon System	4.10	NC
	House with Deep-Pit System	8.20	0.40
Broiler	Poultry House	0.26	NC
Layer-Dry	Poultry House	0.86	NC
Layer-Wet	Poultry House	0.23	NC
Turkey	Poultry House	1.12	NC

NC - Not Calculated.

Specific assumptions and waste management practices for each animal type housed in confinement houses are described below. The following subsection also describes the derivations of the emission factors presented in Table 2.1-4.

Dairies

As shown in Figures 1.3-2 and 1.3-3, the dairy housing for mature cattle is assumed to be freestall barns with flush or scraped manure removal and flushed or hosed milking parlors. Dairy barns using scrape systems to remove manure typically scrape the barn every day (U.S. EPA, 2002a). As shown in Table 2.1-5, 0.13 pounds of nitrogen per day per 1,000 pounds cattle (lb/day/1,000 lb) is lost from fresh dairy manure as compared with scraped manure (NCCES, 1994a Tables 1 and 6). EPA assumed that this nitrogen loss is primarily in the form of ammonia. Table 2.1-5 also shows that ammonia concentrations in the scraped waste and in the fresh manure are essentially the same, indicating that nitrogen is converting to ammonia as manure begins to dry on the barn floor.

Table 2.1-5

Nitrogen Content of Fresh and Scraped Dairy Manure

Constituent	Fresh Manure[a]	Scraped Manure[a]	Difference Between Fresh and Scraped Manure	Percent Difference Between Fresh and Scraped Manure
	(lb/day/1,000 lb)			
Total Kjeldahl Nitrogen	0.45	0.32	0.13	34
Ammonia	0.084	0.077	0.007	8

[a]NCCES, 1994a (Tables 1 and 6).

Dairy barns using flush systems to remove manure typically flush the barns several times per day (U.S. EPA, 2002a). The loss of nitrogen to air for flush barns is expected to be less than that for scraped barns. This nitrogen loss is expected to be in the form of ammonia. Consequently, the confinement barn ammonia emission factors for flush and scrape dairies are calculated separately. A loss of 17.9 percent of the nitrogen in manure is expected from the houses at flush dairies; an emission factor of 31.43 lb NH_3 /yr/head is expected from houses at scrape dairies. See Appendix A for more information on the derivation of these emission factors.

Veal and Swine Operations

Veal and swine operations are represented by two model farms for each animal type: 1) a lagoon system where waste falls into gutters or a sloped underflooring that is flushed several times a day into a lagoon and 2) a deep-pit system where waste collects in deep pits below the pen. ERG used separate ammonia emission factors for these two systems. The emission factor for deep-pit systems is higher than that used for lagoon systems because the manure is expected to remain in the pit for a longer time period, allowing more time for the ammonia to volatilize at the house. For lagoon systems, more ammonia volatilizes from the lagoons once the manure is flushed there. Due to the anaerobic conditions in the veal and swine barns with deep-pit systems, hydrogen sulfide emissions are also expected.

As described in the Cost Methodology Report (U.S. EPA, 2002a), it is assumed that swine operations are located primarily in the Mid-Atlantic, Midwest, and Central regions. In addition, it is assumed that swine operations in the Mid-Atlantic and Midwest regions use either flushing/lagoon systems or deep-pit systems and that all operations in the Central region use flushing systems with evaporative lagoons. The ammonia emission factor for swine houses with lagoon and deep-pit systems are 4.1 lb/yr/head and 8.2 lb/yr/head, respectively. The hydrogen sulfide emission factor for swine houses with deep-pit systems is 0.40 lb/yr/head. See Appendix A for more information on the derivation of these emission factors.

Due to the lack of data available on veal operations, emission factors were transferred from swine operations. A loss of 17.9 percent of the nitrogen present in manure is expected from veal houses with lagoon systems and a loss of 35.7 percent of nitrogen is expected from veal houses with deep-pit systems. A loss of 11.1 percent of the sulfur present in veal manure is lost as hydrogen sulfide from the confinement house. See Appendix A for more information on the derivation of these emission factors.

Poultry Operations

As shown in Figure 1.3-6, the majority of animal waste generated at poultry operations (i.e., broiler, layer, turkey) is deposited and managed as part of the litter used in the poultry houses. The operations use litter systems in which they place clean bedding (e.g., sawdust, wood shavings, or peanut shells) on the floor before adding the flock. Manure, spilled water, and feed become mixed with the bedding while the birds are being raised in the houses. The combination of these four components (i.e., bedding, manure, water, and feed) is referred to as poultry litter. Layer operations typically do not use a litter system and either scrape or flush waste from the poultry house floors. The ammonia emission factor for broiler houses is 0.26 lb/yr/head, for layer-dry houses is 0.86 lb/yr/head, layer-wet houses is 0.23 lb/yr/head, and turkey houses is 1.12 lb/yr/head. See Appendix A for more information on the derivation of these emission factors.

Pond and Lagoon Emissions

Anaerobic lagoons and waste storage ponds are major components of the waste management systems at animal feeding operations. These systems utilize microbes that biodegrade organic nitrogen to ammonium (NH_4^+) and ammonia (NH_3). Ammonia continuously volatilizes from the surface of lagoons and ponds. For this analysis, it is assumed that turkey and broiler operations do not operate waste storage ponds or lagoons; therefore, ammonia emissions are calculated for only beef feedlots, dairies, and heifer, veal, swine, and wet layer operations. The sulfur content of swine, dairy, veal, and layer waste also results in hydrogen sulfide emissions from lagoons.

Many operations currently have settling basins or would be required to install them under several of the regulatory options. Settling basins are estimated to remove 50 percent of the manure solids generated at an operation. The remaining 50 percent of the manure solids collect in the pond or lagoon. Settling basins are estimated to have a 12 percent removal efficiency for nitrogen and a 50 percent removal efficiency for sulfur; therefore 88 percent of the nitrogen excreted in manure and 50 percent of the sulfur excreted is expected to collect in the storage pond or lagoon. In this analysis, the percentage of nitrogen in a pond or lagoon converted to ammonia and the percentage of sulfur converted to hydrogen sulfide is 43.6 percent and 34.1 percent, respectively. See Appendix A for more information on the derivation of these emission factors.

For Option 5, swine and veal wastewater is stored in a covered lagoon, which decreases the amount of nitrogen lost from the lagoon. ERG assumed that 2 percent of the nitrogen entering these covered lagoons is lost as ammonia in biogas (and ultimately transformed to dinitrogen gas and nitrogen oxides).

For Option 6, dairy and swine wastewater is treated in an anaerobic digester before being released to a secondary storage lagoon. Typically, little to no ammonia gas is present in digester gas collected for energy recovery. According to Jewell, et al. (1997), the total nitrogen in the waste stream entering the digester and in the treated effluent (i.e., exiting the digester and entering the secondary storage lagoon) are equal; thus, it is assumed that the quantity of ammonia entering the secondary storage lagoon is the same as that entering the primary lagoon for the other options. As a result, the same ammonia emissions are generated under Option 6 as are generated under the other options.

For operations without solids separation, Equation 2-4 is used to calculate the emission factor for ammonia emissions from ponds and lagoons.

$$\text{EF (no settling) (lb/yr/head)} = \text{Nitrogen}_{\text{input}} \text{ (lb/yr/head)} \times 0.436 \times \frac{17\ NH_3}{14\ N} \qquad [2\text{-}4]$$

where:

$\text{Nitrogen}_{\text{input}}$	=	Amount of nitrogen entering the pond or lagoon (lb/yr-head) from runoff and/or from the confinement house
0.436	=	Fraction of nitrogen in the pond converted to ammonia.

For operations with solids separation, Equation 2-5 is used to calculate the emission factor for ammonia emissions from ponds and lagoons.

$$\text{EF (with settling) (lb/yr/head)} = \text{Nitrogen}_{\text{input}} \text{ (lb/yr/head)} \times 0.88 \times 0.436 \times \frac{17\ \text{NH}_3}{14\ \text{N}} \qquad [2\text{-}5]$$

where:

$\text{Nitrogen}_{\text{input}}$	=	Amount of nitrogen entering the pond or lagoon (lb/yr-head) from runoff and/or from the confinement house
0.88	=	Fraction of nitrogen entering the pond from solids separation
0.436	=	Fraction of nitrogen in the pond converted to ammonia.

Table 2.1-6 presents the methodology used to calculate the amount of nitrogen entering the pond or lagoon by animal type and operation.

Table 2.1-6

Nitrogen Inputs to Ponds and Lagoons

Animal Type	Operation Type	Nitrogen Input Methodology
Dairy	Flush	N in barn - N emitted as NH_3 + N in milking parlor + N in runoff
	Scrape	N in milking parlor + N in runoff
Veal	Lagoon System	N in barn - N emitted as NH_3
Swine	Lagoon System	N in Barn - N emitted as NH_3
Layer-Wet	Flush	N in house - N emitted as NH_3

For operations without solids separation, hydrogen sulfide emission factors are calculated using Equation 2-6:

$$\text{EF (no settling) (lb/yr/head)} = \text{Sulfur}_{\text{input}} \text{ (lb/yr/head)} \times 0.341 \times \frac{17\ \text{H}_2\text{S}}{16\ \text{S}} \qquad [2\text{-}6]$$

where:

$\text{Sulfur}_{\text{input}}$	=	Amount of sulfur entering the lagoon
0.341	=	Fraction of sulfur converted to hydrogen sulfide.

For operations with solids separation, hydrogen sulfide emission factors are calculated using Equation 2-7:

$$\text{EF (with settling) (lb/yr/head)} = \text{Sulfur}_{input} \text{ (lb/yr/head)} \times 0.50 \times 0.341 \times \frac{17\ H_2S}{16\ S} \qquad [2\text{-}7]$$

where:

Sulfur_{input}	=	Amount of sulfur entering the lagoon
0.50	=	Fraction of sulfur entering the pond from solids separation
0.341	=	Fraction of sulfur converted to hydrogen sulfide.

For this analysis it is assumed that all of the sulfur generated at the barn is sent to either solids separation or to the lagoon. None is emitted as hydrogen sulfide. Therefore, the amount of sulfur entering the lagoon is equal to the amount of sulfur excreted by the animals.

Tables 2.1-7 and 2.1-8 present the ammonia and hydrogen sulfide emission factors by animal type and operation type.

Specific assumptions regarding ponds and lagoons for each animal type are described below. The following subsection also describes the derivations of the emission factors presented in Tables 2.1-7 and 2.1-8.

Beef Feedlots and Heifer Operations

At beef feedlots and heifer operations, only the runoff from the drylot enters the storage ponds. At baseline, the beef feedlots and heifer operations are grouped into high-, medium-, and low-requirement operations, reflecting the status of their waste management system in controlling effluent. It is assumed that 100 percent of low-requirement operations already have a settling basin, 80 percent of medium-requirement operations have a settling basin in place, and 40 percent of high-requirement operations have a settling basin in place. These requirements are discussed in more detail in the Cost Methodology Report (U.S. EPA, 2002a).

Table 2.1-7

Ammonia Emission Factors for Ponds and Lagoons by Animal Type and by Region

Animal Type	Operation Type	Ammonia Emission Factors (lb/yr/head)				
		Central	Mid-Atlantic	Midwest	Pacific	South
Beef	Solids Separation	3.6	11.5	6.0	12.4	13.7
	No Solids Separation	4.0	13.1	6.8	14.1	15.6
Heifer	Solids Separation	2.8	9.2	4.8	9.9	10.9
	No Solids Separation	3.2	10.4	5.4	11.2	12.4
Dairy-Flush	Solids Separation	89.6	93.9	90.9	94.4	95.1
	No Solids Separation	101.5	105.9	102.8	106.4	107.0
Dairy-Scrape	Solids Separation	17.5	21.8	18.8	22.3	23.0
	No Solids Separation	19.6	23.9	20.9	24.4	25.1
Veal	Solids Separation	9.8	9.8	9.8	9.8	9.8
Swine - Grow Finish	No Solids Separation	10.0	10.0	10.0	10.0	10.0
Swine - Farrow-to-Finish	No Solids Separation	10.0	10.0	10.0	10.0	10.0
Layers-Wet	No Solids Separation	0.5	0.5	0.5	0.5	0.5

Table 2.1-8

Hydrogen Sulfide Emission Factors for Ponds and Lagoons by Animal Type

Operation Type	Hydrogen Sulfide Emission Factors by Animal Type (lb/yr/head)				
	Dairy - Flush	Dairy - Scrape	Veal	Swine	Layer-Wet
Solids Separation	4.6	0.7	1.2	NA	NA
No Solids Separation	9.1	1.4	NC	1.2	0.07

NA - Not applicable.
NC - Not calculated.

Dairies

Both scrape and flush dairies, send the wastewater from flushing the parlors to the lagoon, along with runoff from the drylot. Flush dairies also send wastewater from flushing the barn to the lagoon. At baseline, it is assumed that 33 percent of Large and 20 percent of Medium operations have a settling basin in place prior to the lagoon. These requirements are discussed in more detail in the Cost Methodology Report (U.S. EPA, 2002a).

Veal Operations

Only veal operations with flush systems have lagoons in the production area; therefore, there are no lagoon emission factors for veal operations with deep-pit storage systems. At flush veal operations, only the wastewater from flushing the barn is sent to the lagoon. It is assumed that all lagoon veal operations have a settling basin in place at baseline and under all regulatory options.

Swine Operations

Only swine operations with flush systems have lagoons in the production area; therefore, there are no lagoon emission factors for swine operations with deep-pit storage systems. At swine operations with flush systems, only wastewater from washing the storage pits is sent to the lagoon. For this analysis, it is assumed that swine operations do not have solids separation.

Layers-Wet Operations

At poultry operations using a wet layer system, waste is flushed out of the layer house and stored in a lagoon. For this analysis, it is assumed that wet layer poultry operations do not have solids separation.

Composting Emissions

Composting is considered under Option 5A for beef feedlots, heifer operations, and dairies. Under Option 5A, the manure scraped from barns and drylots and the separated solids from the settling basin are composted. Ammonia emission factors for composting are based on an average air loss of 30 percent of the nitrogen in the compost over three years (Eghball, 1997). For beef feedlots, heifer operations, and flush dairies, the total amount of nitrogen entering the compost is calculated by adding the nitrogen in the separated solids (as TKN) and the nitrogen in the manure scraped from barns and drylots. For scrape dairies, the calculation includes the nitrogen in the manure that is scraped from the confinement barn.

The compost ammonia emissions are calculated using Equation 2-8:

$$\text{Compost Emissions (lb/yr)} = \text{Nitrogen}_{\text{Compost}} \text{ (lb/yr)} \times 0.30 \times \frac{17\ NH_3}{14\ N} \qquad [2\text{-}8]$$

where:

$\text{Nitrogen}_{\text{Compost}}$	=	Amount of nitrogen sent to composting
0.30	=	Fraction of nitrogen lost from composting.

Table 2.1-9 presents the methodology used to calculate the amount of nitrogen sent to composting by animal type.

Table 2.1-9

Amount of Nitrogen Sent to Composting by Animal Type

Animal Type	Nitrogen Input Methodology
Beef	N entering solids separator from runoff + N scraped from drylot
Heifer	N entering solids separator from runoff + N scraped from drylot
Dairy - Flush	N entering solids separator (N excreted in Barn - N emitted as NH_3 + N excreted in Milking Parlor) + N scraped from drylot
Dairy - Scrape	N entering solids separator (N excreted in Milking Parlor) + N scraped from drylot + N scraped from barn (N excreted in Barn - N emitted as NH_3)

The nitrogen content in manure that is scraped from drylots and placed in the compost is 55 percent of what was originally excreted, because 45 percent was emitted as NH_3 from the drylot, as described in the Drylot Emission section.

The following general equation is used to calculate the nitrogen in separated solids ($Nitrogen_{separator}$):

$$\text{TKN in Separated Solids (SS)} = \frac{\text{Input N into SS x \% N Removed}}{100} \qquad [2\text{-}9]$$

where:

TKN in Separated Solids	=	Nitrogen in solids removed from the separator ($Nitrogen_{separator}$)
Input N into SS	=	Amount of nitrogen entering the solids separator
% N Removed	=	Separated solids from the separator estimated to have a nitrogen content that is 12 percent of the nitrogen that enters the separator (Van Horn, 1998).

Table 2.1-10 presents the composting emission factors by animal type and region.

Table 2.1-10

Ammonia Composting Emission Factors for Beef Feedlots, Heifer Operations, and Dairies by Region

Animal Type	Ammonia Composting Emission Factors (lb/yr/head)				
	Central	Mid-Atlantic	Midwest	Pacific	South
Beef	22.41	23.16	22.64	23.24	23.36
Heifer	12.73	13.33	12.92	13.40	13.49
Dairy - Flush	14.03	14.03	14.03	14.03	14.03
Dairy - Scrape	66.50	66.50	66.50	66.50	66.50

Stockpile Emissions

For this analysis, it is assumed that beef feedlots, dairies, and heifer and veal operations stockpile animal waste under all regulatory options. It is also assumed that the amount of material stockpiled does not change from current practices under any of the regulatory options, except Option 5A. Under Option 5A, all waste that is currently stockpiled will be composted; therefore, no ammonia emissions for stockpiles are calculated for Option 5A.

Stockpile emission factors are calculated using the amount of nitrogen separated out in the settling basin (where applicable) and the nitrogen in the manure scraped from the drylot and/or the confinement barn. Under Options 1, 2, 5A, and 7, it is assumed that these wastes are stockpiled on the ground. Under Options 3 and 4, it is assumed that the manure scraped from the drylots is stockpiled on the ground, and the wastes from the barn and the separated solids from the settling basins are stockpiled on an impermeable pad (e.g., concrete pad).

Although concrete pads have negligible leachate, the volatilization potential remains almost the same as the stockpile; therefore, for a specific region, the percentage of ammonia that volatilizes from stockpiles and concrete pads is the same. The negligible leachate from concrete pads results in a slightly higher nitrogen content of waste for land application.

The stockpile ammonia emission rates used in this analysis are based on information from a literature review (Sutton et al., 2001), which indicated that 20 to 40 percent of nitrogen is lost from solids manure storage. The nitrogen loss is related to the amount of time the material is stored. For this analysis, an emission factor of 20 percent was used.

For beef feedlots, heifer operations, and flush dairies, the total amount of nitrogen entering the stockpile is calculated by adding the nitrogen in the separated solids (as TKN) and the nitrogen in the manure scraped from the drylots. For scrape dairies, the calculation includes the amount of nitrogen in the manure scraped from the confinement barn. At veal operations, only separated solids are stockpiled; therefore, the amount of nitrogen entering the stockpile is equal to the amount of nitrogen in the separated solids (as TKN). The stockpile ammonia emission factors are calculated using Equation 2-10:

$$\text{Stockpile Emissions} = \text{Nitrogen}_{\text{Stockpile}}\ (\text{lb/yr}) \times 0.20 \times \frac{17\ NH_3}{14\ N} \qquad [2\text{-}10]$$

where:

$\text{Nitrogen}_{\text{Stockpile}}$ = Amount of nitrogen entering the stockpile
0.20 = Fraction of ammonia emitted from the stockpile.

Table 2.1-11 presents the methodology used to calculate the amount of nitrogen sent to the stockpile by animal type.

The amount of nitrogen going to the stockpile from drylots (beef, heifer, and dairies) and confinement barns (scrape dairies) is equal to that going to the compost pile under Option 5A. The nitrogen content in manure that is scraped from drylots and placed in the stockpile is 55 percent of what was originally excreted, because 45 percent was emitted as NH_3 from the drylot. For all animal types, 12 percent of the nitrogen that is flushed to the settling basin will be separated and sent to the stockpile.

Table 2.1-11

Amount of Nitrogen Sent to the Stockpile by Animal Type

Animal Type	Nitrogen Input Methodology
Beef	N entering solids separator from runoff + N scraped from drylot
Heifer	N entering solids separator from runoff + N scraped from drylot
Dairy - Flush	N entering solids separator (N excreted in barn - N emitted as NH_3 + N excreted in milking parlor) + N scraped from drylot
Dairy - Scrape	N entering solids separator (N excreted in milking parlor) + N scraped from drylot + N scraped from barn (N excreted in barn - N emitted as NH_3)

Table 2.1-12 presents the ammonia stockpile emission factors by animal type and region.

Table 2.1-12

Ammonia Stockpile Emission Factors for Beef Feedlots, Dairies, and Heifer and Operations by Region

Animal Type	Ammonia Stockpile Emission Factors (lb/yr/head)				
	Central	Mid-Atlantic	Midwest	Pacific	South
Beef	0.22	0.72	0.37	0.78	0.86
Heifer	0.18	0.57	0.30	0.62	0.68
Dairy - Flush	5.48	5.48	5.48	5.48	5.48
Dairy - Scrape	40.46	40.46	40.46	40.46	40.46
Veal - Flush	0.61	0.61	0.61	0.61	0.61
Veal - Scrape	0.48	0.48	0.48	0.48	0.48

2.1.3 Calculation of Model Farm Results

Using the methodology outlined above, emissions are calculated for each animal at a model farm in each region for each regulatory option (as defined in Section 1).

Ammonia Emissions from Beef Feedlots, Heifer Operations, and Dairies

Table 2.1-13 presents the ammonia emission estimates by regulatory option and model farm for beef feedlots, heifer operations, and dairies.

Baseline:

At baseline, the beef feedlots and heifer operations are grouped into high-, medium-, and low-requirement operations, reflecting the status of their waste management system in controlling effluent. It is assumed that 100 percent of low-requirement operations already have a settling basin, 80 percent of medium-requirement operations have a settling basin in place, and 40 percent of high-requirement operations have a settling basin in place. Therefore, when estimating baseline model farm emissions, emission factors calculated for both operations with separation and operations without separation must be used. The emissions are generated for high-, medium-, and low- requirement operations separately, then summed. Equation 2-11 is used to estimate emissions from a high- requirement operation:

$$\begin{aligned}&\text{High Requirement Model Farm Ammonia Emissions (ton/yr)}\\ &= [(EF_{\text{drylot with settling}} + EF_{\text{stockpile with settling}} + EF_{\text{pond with settling}}) \times \text{Avg. Head} \times \text{\% Settling}]\\ &+ [(EF_{\text{drylot without settling}} + EF_{\text{stockpile without settling}} + EF_{\text{pond without settling}} \times \text{Avg. Head} \times (1 - \text{\% Settling})]\\ &\div 2{,}000 \text{ lb/ton}\end{aligned} \quad [2\text{-}11]$$

Equation 2-11 is also used to estimate emissions from medium- and low-requirement operations. The sum of the high-, medium-, and low-requirement operations emissions is equal to the total emissions expected at baseline.

Table 2.1-13

Ammonia Emissions from Beef Feedlots, Heifer Operations, and Dairies by Regulatory Option and Model Farm (lb/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef - Large CAFOs							
	Large 2	Baseline	1,402,984	1,096,383	1,309,170	1,060,711	N/A
		Options 1-4, 6-7	1,397,884	1,079,879	1,300,581	1,042,882	N/A
		Option 5A	1,972,489	1,660,927	1,877,157	1,624,678	N/A
	Large 1	Baseline	99,615	77,846	92,954	75,313	N/A
		Options 1-4, 6-7	99,253	76,674	92,344	74,047	N/A
		Option 5A	140,051	177,930	133,283	115,356	N/A
Beef - Medium CAFOs							
	Medium 3	Baseline	41,507	32,436	38,732	31,381	29,954
		Options1-4, 6-7	41,356	31,948	38,477	30,853	29,373
		Option 5A	58,356	49,138	55,535	48,066	46,615
	Medium 2	Baseline	29,902	23,368	27,903	22,607	21,579
		Options 1-4, 6-7	29,794	23,016	27,720	22,227	21,161
		Option 5A	42,040	35,400	40,009	34,627	33,582
	Medium 1	Baseline	20,020	15,645	18,681	15,136	14,448
		Options 1-4, 6-7	19,947	15,410	18,559	14,882	14,168
		Option 5A	28,147	23,701	26,786	23,184	22,484
Heifer - Large CAFOs							
	Large 1	Baseline	44,695	N/A	N/A	28,935	N/A
		Options 1-4, 6-7	44,460	N/A	N/A	28,114	N/A
		Option 5A	63,296	N/A	N/A	47,281	N/A
Heifer - Medium CAFOs							
	Medium 3	Baseline	26,072	N/A	23,552	16,879	N/A
		Options 1-4, 6-7	25,935	N/A	23,322	16,400	N/A
		Option 5A	36,923	N/A	34,362	27,581	N/A
	Medium 2	Baseline	18,623	N/A	16,823	12,056	N/A
		Options 1-4, 6-7	18,525	N/A	16,658	11,714	N/A
		Option 5A	26,373	N/A	24,544	19,701	N/A

Table 2.1-13 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Heifer - Medium CAFOs (cont.)							
	Medium 1	Baseline	11,919	N/A	10,767	7,716	N/A
		Options 1-4, 6-7	11,856	N/A	10,661	7,497	N/A
		Option 5A	16,879	N/A	15,708	12,608	N/A
Dairy - Large CAFOs							
	Large 1	Baseline	198,925	172,905	178,506	189,915	190,897
		Options 1-4, 6-7	194,034	169,286	174,888	185,024	186,006
		Option 5A	222,939	214,868	220,469	213,929	214,911
Dairy - Medium CAFOs							
	Medium 3	Baseline	76,230	65,209	67,559	77,449	72,861
		Options 1-4, 6-7	74,417	64,033	66,383	70,636	71,048
		Option 5A	93,542	90,156	92,506	89,762	90,174
	Medium 2	Baseline	54,033	46,221	47,887	51,354	51,646
		Options 1-4, 6-7	52,748	45,388	47,054	500,069	550,361
		Option 5A	66,305	63,904	65,570	63,625	63,917
	Medium 1	Baseline	31,812	27,213	28,194	30,235	30,407
		Options 1-4, 6-7	31,056	26,722	27,703	29,478	29,650
		Option 5A	39,037	37,624	38,605	37,460	37,631

N/A - Not Applicable

The emissions from flush dairies and scrape dairies are both calculated using the different production area emission factors for each dairy type. The emissions from flush dairies and scrape dairies are then summed to calculate the total dairy emissions from the production area.

At baseline, it is assumed that 20 percent of Medium and 33 percent of Large operations have a settling basin in place. Therefore, the emission factors for operations with a settling basin and without a settling basin are both needed to calculate baseline emissions, using a methodology similar to that used for beef feedlots and heifer operations shown above. The drylot, house, lagoon, and stockpile emission factors are used in these calculations.

Options 1-4, 6-7:

For all regulatory options, it is assumed that all beef feedlots, heifer operations, and dairies have a settling basin in place. Therefore, only the emission factors for operations with separation are used in Equation 2-12.

$$\begin{aligned}&\text{Model Farm Ammonia Emissions (ton/yr)}\\&= [(\text{Drylot EF} + \text{Stockpile w/separation EF} + \text{Pond w/separation EF}) \times \text{Avg Head} \div (2{,}000 \text{ lb/ton})\end{aligned} \quad [2\text{-}12]$$

The model farm emissions from flush and scrape dairies are calculated separately, then summed to get the total model farm emissions from the production area.

Option 5A:

For Option 5A, it is assumed that all beef feedlots, heifer operations, and dairies compost their waste rather than sending it to a stockpile, as shown in Equation 2-13.

$$\begin{aligned}&\text{Model Farm Ammonia Emissions (ton/yr)}\\&= [(\text{Drylot EF} + \text{Pond w/separation EF} + \text{Compost EF}) \times \text{Avg Head} \div 2{,}000 \text{ lb/ton}\end{aligned} \quad [2\text{-}13]$$

Again, the model farm emissions from flush and scrape dairies are calculated separately, then summed to get the total model farm emissions from the production area.

Ammonia Emissions from Veal, Swine and Layer Operations

Table 2.1-14 presents the ammonia emissions from veal, swine, and layer operations.

Baseline and Options 1-4, 6-7:

Veal, swine, and layer operations have both lagoon operations and deep-pit operations. For each animal type, the emissions from the lagoon operations and the deep-pit operations are calculated using the different production area emission factors specific to each type of operation. The lagoon and deep-pit emissions are then summed to calculate the total emissions from the production area. The house, lagoon, and stockpile emission factors are used to calculate veal emissions, and the house and lagoon emission factors are used to calculate swine and layer emissions. The methodology used to generate the emissions is similar to that used for beef feedlots, heifer operations, and dairies, as presented in Equation 2-14.

$$\text{Model Farm Ammonia Emissions (ton/yr)} = (\text{House EF} + \text{Lagoon EF}) \times \text{Avg Head} \div 2{,}000 \text{ lb/ton} \quad [2\text{-}14]$$

Option 5:

Under Option 5, all lagoons are covered and the gas emitted is collected and flared. Therefore, no ammonia emissions are generated from the lagoons under this option. Only the housing emission factors are used to calculate the model farm emissions as presented in Equation 2-15.

$$\text{Model Farm Ammonia Emissions (ton/yr)} = (\text{House EF}) \times \text{Avg Head} \div 2{,}000 \text{ lb/ton} \quad [2\text{-}15]$$

Table 2.1-14

Ammonia Emissions from Veal, Swine, and Layer Operations by Regulatory Option and Model Farm (lb/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow Finish - Large CAFOs							
	Large 2	Baseline	414,385	112,206	106,785	N/A	N/A
		Options 1-4, 6-7	414,385	112,206	105,785	N/A	N/A
		Option 5A	120,495	45,624	65,874	N/A	N/A
	Large 1	Baseline	48,716	44,856	36,092	N/A	N/A
		Options 1-4, 6-7	48,716	44,856	36,092	N/A	N/A
		Option 5A	14,166	18,224	22,410	N/A	N/A
Swine - Grow Finish - Medium CAFOs							
	Medium 3	Baseline	N/A	27,554	22,441	N/A	N/A
		Options 1-4, 6-7	N/A	27,355	22,441	N/A	N/A
		Option 5A	N/A	11,206	13,925	N/A	N/A
	Medium 2	Baseline	N/A	19,185	15,021	N/A	N/A
		Options 1-4, 6-7	N/A	19,185	15,021	N/A	N/A
		Option 5A	N/A	7,807	9,325	N/A	N/A
	Medium 1	Baseline	N/A	12,158	9,503	N/A	N/A
		Options 1-4, 6-7	N/A	12,158	9,503	N/A	N/A
		Option 5A	N/A	4,935	5,905	N/A	N/A
Swine - Farrow-to-Finish - Large CAFOs							
	Large 2	Baseline	117,002	221,024	149,999	N/A	N/A
		Options 1-4, 6-7	117,002	221,024	149,999	N/A	N/A
		Option 5A	34,022	84,318	87,824	N/A	N/A
	Large 1	Baseline	51,127	45,298	37,376	N/A	N/A
		Options 1-4, 6-7	51,127	45,298	37,376	N/A	N/A
		Option 5A	14,867	17,291	21,892	N/A	N/A
Swine - Farrow-to-Finish - Medium CAFOs							
	Medium 3	Baseline	N/A	28,014	23,359	N/A	N/A
		Options 1-4, 6-7	N/A	28,014	23,359	N/A	N/A
		Option 5A	N/A	10,623	13,677	N/A	N/A

Table 2.1-14 (Continued)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Farrow-to-Finish - Medium CAFOs (cont.)							
	Medium 2	Baseline	N/A	19,595	15,847	N/A	N/A
		Options 1-4, 6-7	N/A	19,595	15,847	N/A	N/A
		Option 5A	N/A	7,481	9,279	N/A	N/A
	Medium 1	Baseline	N/A	10,933	8,836	N/A	N/A
		Options 1-4, 6-7	N/A	10,933	8,836	N/A	N/A
		Option 5A	N/A	4,161	5,173	N/A	N/A
Veal - Medium CAFOs							
	Medium 3	Baseline	15,675	N/A	15,675	N/A	N/A
		Options 1-4, 6-7	15,675	N/A	15,675	N/A	N/A
		Option 4	8,408	N/A	8,408	N/A	N/A
	Medium 2	Baseline	7,838	N/A	7,838	N/A	N/A
		Options 1-4, 6-7	7,838	N/A	7,838	N/A	N/A
		Option 5A	4,204	N/A	4,204	N/A	N/A
	Medium 1	Baseline	5,806	5,806	5,806	N/A	N/A
		Options 1-4, 6-7	5,806	5,806	5,806	N/A	N/A
		Option 5A	3,114	3,114	3,114	N/A	N/A
Layer - Dry - Large CAFOs							
	Large 2	Baseline	N/A	N/A	968,949	N/A	968,949
		Options 1-4, 6-7	N/A	N/A	968,949	N/A	968,949
		Option 5A	N/A	N/A	968,949	N/A	968,949
	Large 1	Baseline	N/A	N/A	203,039	N/A	203,039
		Options 1-4, 6-7	N/A	N/A	203,039	N/A	203,039
		Option 5A	N/A	N/A	203,039	N/A	203,039
Layer - Dry - Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	72,889	N/A	72,889
		Options 1-4, 6-7	N/A	N/A	72,889	N/A	72,889
		Option 4	N/A	N/A	72,889	N/A	72,889
	Medium 2	Baseline	N/A	N/A	42,266	N/A	42,266
		Options 1-4, 6-7	N/A	N/A	42,266	N/A	42,266
		Option 5A	N/A	N/A	42,266	N/A	42,266

Table 2.1-14 (Continued)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Dry - Medium CAFOs (cont.)							
	Medium 1	Baseline	N/A	N/A	28,444	N/A	28,444
		Options 1-4, 6-7	N/A	N/A	28,444	N/A	28,444
		Option 5A	N/A	N/A	28,444	N/A	28,444
Layer - Wet - Large CAFOs							
	Large 1	Baseline	N/A	N/A	N/A	N/A	64,298
		Option s1-4, 6-7	N/A	N/A	N/A	N/A	64,298
		Option 5A	N/A	N/A	N/A	N/A	19,928
Layer - Wet - Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	N/A	N/A	2,704
		Options 1-4, 6-7	N/A	N/A	N/A	N/A	2,704
		Option 5A	N/A	N/A	N/A	N/A	838

N/A - Not Applicable.

Ammonia Emissions from Broiler and Turkey Operations

Table 2.1-15 presents the ammonia emissions from broiler and turkey operations.

Baseline and 1-7:

Because broiler and turkey operations have dry housing and do not operate lagoons, stockpiles, or compost piles, the emissions from the production area do not vary by option.

$$\text{Model Farm Ammonia Emissions (ton/yr)} = \text{House EF} \times \text{Avg Head} \div 2{,}000 \text{ lb/ton} \qquad [2\text{-}16]$$

Hydrogen Sulfide Emissions from Dairy, Veal, Swine, and Layer Operations

Lagoon hydrogen sulfide emission factors have been identified for the following animal types: dairy-flush, veal-flush, layer-wet, and swine-lagoon. A house hydrogen sulfide emission factor has been identified for veal-pit and swine-pit operations. Model farm hydrogen sulfide emissions are calculated using these emission factors and the average head numbers for each model farm. Table 2.1-16 presents the hydrogen sulfide emissions from dairies, veal, swine, and layer operations.

Dairy

At baseline, it is assumed that 20 percent of Medium and 33 percent of Large operations have a settling basin in place. Therefore, the emission factors for operations with a settling basin and without a settling basin are both needed to calculate baseline emissions. The methodology is similar to that used for calculating ammonia emissions.

Table 2.1-15

Ammonia Emissions from Broiler and Turkey Operations by Regulatory Option and Model Farm (lb/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Broiler - Large CAFOs							
	Large 1	Baseline	N/A	31,384	N/A	N/A	31,087
		Options 1-4, 6-7	N/A	31,384	N/A	N/A	31,087
		Option 5A	N/A	31,384	N/A	N/A	31,087
Broiler - Medium CAFOs							
	Medium 3	Baseline	N/A	21,163	N/A	N/A	21,221
		Options 1-4, 6-7	N/A	21,163	N/A	N/A	21,221
		Option 5A	N/A	21,163	N/A	N/A	21,221
	Medium 2	Baseline	N/A	13,523	N/A	N/A	13,465
		Options 1-4, 6-7	N/A	13,523	N/A	N/A	13,465
		Option 5A	N/A	13,523	N/A	N/A	13,465
	Medium 1	Baseline	N/A	10,278	N/A	N/A	10,233
		Options 1-4, 6-7	N/A	10,278	N/A	N/A	10,233
		Option 5A	N/A	10,278	N/A	N/A	10,233
Turkey - Large CAFOs							
	Large 1	Baseline	N/A	148,247	148,247	N/A	N/A
		Options 1-4, 6-7	N/A	148,247	148,247	N/A	N/A
		Option 5A	N/A	148,247	148,247	N/A	N/A
Turkey - Medium CAFOs							
	Medium 3	Baseline	N/A	50,658	50,658	N/A	N/A
		Options 1-4, 6-7	N/A	50,658	50,658	N/A	N/A
		Option 4	N/A	50,658	50,658	N/A	N/A
	Medium 2	Baseline	N/A	34,557	34,557	N/A	N/A
		Options 1-4, 6-7	N/A	34,557	34,557	N/A	N/A
		Option 5A	N/A	34,557	34,557	N/A	N/A
	Medium 1	Baseline	N/A	20,491	20,491	N/A	N/A
		Options 1-4, 6-7	N/A	20,491	20,491	N/A	N/A
		Option 5A	N/A	20,491	20,491	N/A	N/A

N/A - Not Applicable.

Table 2.1-16

Hydrogen Sulfide Emissions from Dairies, Veal, Swine, and Layer Operations by Regulatory Option and Model Farm (lb/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Dairy - Large CAFOs							
	Large 1	Baseline	8,575	6,260	6,260	8,575	8,575
		Options 1-4, 6-7	5,173	3,775	3,775	5,173	5,173
		Option 5A	5,173	3,775	3,775	5,173	5,173
Dairy - Medium CAFOs							
	Medium 3	Baseline	2,829	1,783	1,783	2,829	2,829
		Options 1-4, 6-7	1,584	998	998	1,584	1,584
		Option 5A	1,584	998	998	1,584	1,584
	Medium 2	Baseline	2,005	1,264	1,264	2,005	2,005
		Options 1-4, 6-7	1,123	707	707	1,123	1,123
		Option 5A	1,123	707	707	1,123	1,123
	Medium 1	Baseline	1,181	744	744	1,181	1,181
		Options 1-4, 6-7	661	416	416	661	661
		Option 5A	661	416	416	661	661
Swine - Grow Finish - Large CAFOs							
	Large 2	Baseline	35,267	8,861	7,144	N/A	N/A
		Options 1-4, 6-7	35,267	8,861	7,144	N/A	N/A
		Option 5A	0	872	2,355	N/A	N/A
	Large 1	Baseline	4,146	3,543	2,441	N/A	N/A
		Options 1-4, 6-7	4,146	3,543	2,441	N/A	N/A
		Option 5A	0	347	799	N/A	N/A
Swine - Grow Finish - Medium CAFOs							
	Medium 3	Baseline	N/A	2,176	1,518	N/A	N/A
		Options 1-4, 6-7	N/A	2,176	1,518	N/A	N/A
		Option 5A	N/A	214	496	N/A	N/A
	Medium 2	Baseline	N/A	1,515	1,016	N/A	N/A
		Options 1-4, 6-7	N/A	1,515	1,016	N/A	N/A
		Option 5A	N/A	149	332	N/A	N/A

Table 2.1-16 (Continued)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow Finish - Medium CAFOs (cont.)							
	Medium 1	Baseline	N/A	961	642	N/A	N/A
		Options 1-4, 6-7	N/A	961	642	N/A	N/A
		Option 5A	N/A	94	211	N/A	N/A
Swine - Farrow-to-Finish - Large CAFOs							
	Large 2	Baseline	9,958	17,749	10,426	N/A	N/A
		Options 1-4, 6-7	9,958	17,749	10,426	N/A	N/A
		Option 5A	0	1,344	2,965	N/A	N/A
	Large 1	Baseline	4,351	3,637	2,597	N/A	N/A
		Options 1-4, 6-7	4,351	3,637	2,597	N/A	N/A
		Option 5A	0	276	739	N/A	N/A
Swine - Farrow-to-Finish - Medium CAFOs							
	Medium 3	Baseline	N/A	2,253	1,624	N/A	N/A
		Options 1-4, 6-7	N/A	2,253	1,624	N/A	N/A
		Option 5A	N/A	166	462	N/A	N/A
	Medium 2	Baseline	N/A	1,573	1,101	N/A	N/A
		Options 1-4, 6-7	N/A	1,573	1,101	N/A	N/A
		Option 5A	N/A	120	313	N/A	N/A
	Medium 1	Baseline	N/A	878	614	N/A	N/A
		Options 1-4, 6-7	N/A	878	614	N/A	N/A
		Option 5A	N/A	66	175	N/A	N/A
Veal - Medium CAFOs							
	Medium 3	Baseline	1,135	N/A	1,135	N/A	N/A
		Options 1-4, 6-7	1,135	N/A	1,135	N/A	N/A
		Option 5A	274	N/A	274	N/A	N/A
	Medium 2	Baseline	568	N/A	568	N/A	N/A
		Options 1-4, 6-7	568	N/A	568	N/A	N/A
		Option 5A	137	N/A	137	N/A	N/A
	Medium 1	Baseline	420	420	420	N/A	N/A
		Options 1-4, 6-7	420	420	420	N/A	N/A
		Option 5A	101	101	101	N/A	N/A

Table 2.1-16 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Wet - Large CAFOs							
	Large 1	Baseline	N/A	N/A	N/A	N/A	6,242
		Options 1-4, 6-7	N/A	N/A	N/A	N/A	6,242
		Option 5A	N/A	N/A	N/A	N/A	0
Layer - Wet - Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	N/A	N/A	257
		Options 1-4, 6-7	N/A	N/A	N/A	N/A	257
		Option 4	N/A	N/A	N/A	N/A	0
	Medium 2	Baseline	N/A	N/A	N/A	N/A	0
		Options 1-4, 6-7	N/A	N/A	N/A	N/A	0
		Option 5A	N/A	N/A	N/A	N/A	0
	Medium 1	Baseline	N/A	N/A	N/A	N/A	0
		Options 1-4, 6-7	N/A	N/A	N/A	N/A	0
		Option 5A	N/A	N/A	N/A	N/A	0

N/A - Not Applicable.

Baseline:

$$\text{Model Farm Hydrogen Sulfide Emissions (ton/yr)} = [(\text{Lagoon } EF_{\text{with settling}}) \times \text{Avg Head} \times \%\ \text{Separation}] + [(\text{Lagoon } EF_{\text{without settling}}) \times \text{Avg Head} \times (1 - \%\ \text{Separation})] \div 2{,}000 \text{ lb/ton} \quad [2\text{-}17]$$

Options 1-7:

All dairies are assumed to have a settling basin and emissions are calculated as shown in Equation 2-18.

$$\text{Model Farm Hydrogen Sulfide Emissions (ton/yr)} = \text{Lagoon EF (lb/yr-head)} \times \text{Avg Head} \div 2{,}000 \text{ lb/ton} \quad [2\text{-}18]$$

<u>Veal and Swine</u>

For each animal type, the emissions from the lagoon operations and the deep-pit operations are calculated using the different production area emission factors specific to each type of operation. The lagoon and deep-pit emissions are then summed to calculate the total emissions from the production area using Equation 2-19. Under Option 5, the lagoon is covered; therefore, there are no emissions from the lagoon and emissions are only calculated for the deep-pit house.

Baseline and Options 1-4, 6-7:

$$\text{Model Farm Hydrogen Sulfide Emissions (ton/yr)} = (\text{Lagoon EF} + \text{House-Pit EF}) \times \text{Avg Head} \div 2{,}000 \text{ lb/ton} \quad [2\text{-}19]$$

Option 5:

$$\text{Model Farm Hydrogen Sulfide Emissions (ton/yr)} = \text{House-Pit EF} \times \text{Avg Head} \div 2{,}000 \text{ lb/ton}$$

Wet Layers

No hydrogen sulfide emissions are expected from dry layer operations. Hydrogen sulfide emissions are generated only from the lagoons used at wet layer operations and are calculated using Equation 2-20. Under Option 5, the lagoons are covered; therefore, there are no hydrogen sulfide emissions from wet layer operations.

Baseline and Options 1-4, 6-7:

$$\text{Model Farm Hydrogen Sulfide Emissions (ton/yr)} = \text{Lagoon EF} \times \text{Avg Head} \div 2{,}000\ \text{lb/ton} \qquad [2\text{-}20]$$

Option 5:

$$\text{Model Farm Hydrogen Sulfide Emissions (ton/yr)} = 0$$

2.2 Greenhouse Gas Emissions from Manure Management Systems

Manure management systems, including animal confinement areas, produce methane (CH_4) and nitrous oxide (N_2O) emissions. This subsection presents the data inputs and the calculation methodology used to estimate greenhouse gas emissions from manure management systems, as well as a summary of the model farm results. Greenhouse gas emissions for methane and nitrous oxide presented in this report are based on the guidance developed for international reporting of greenhouse gas emissions (IPCC, 2000) and methodologies developed by EPA's Office of Air and Radiation (U.S. EPA, 2002b). Appendix B presents example calculations. All greenhouse gas emissions are reported in units of Tg-CO_2 equivalent, which normalizes the emissions to carbon dioxide.

2.2.1 Data Inputs

The estimation of greenhouse gas emissions from manure management systems uses a number of data inputs, including:

- Animal weight;
- Volatile solids excretion rate;
- Nitrogen excretion rate;
- Maximum methane-producing potential (B_o);
- Runoff solids generation; and
- Manure composted.

Table 2.2-1 presents the waste characteristics data used in the greenhouse gas emission calculations for each of the animal types modeled. ERG obtained volatile solids and nitrogen excretion rate data from the Agricultural Waste Management Field Handbook (USDA, 1996). These factors are combined with average animal weight to estimate the amount of volatile solids (VS) and total Kjeldahl nitrogen (TKN) excreted by the animals. Certain model farms, such as swine - farrow-to-finish operations and layer operations, house a combination of animals. For example, swine - farrow-to-finish operations have sows, boars, gilts, nursery pigs, and growing pigs present. ERG estimates the average waste characteristics present at these

Table 2.2-1

Waste Characteristics Data Used in Greenhouse Gas Emission Calculations

Animal Type	Average Animal Weight (kg)	As Excreted		Entering Compost Operation		B_o (m^3 CH_4/kg VS excreted)	Reference for B_o
		Volatile Solids (kg/day/1,000 kg)[a]	Nitrogen (kg/day/1,000 kg)[a]	Volatile Solids (lb/ton manure)[b]	Nitrogen (lb/ton manure)[b]		
Mature dairy cow	612	8.45	0.45	564.6	25.71	0.24	Morris, 1976
Heifer	306	7.77	0.31	564.6	25.71	0.17	Bryant, et.al., 1976
Calf	159	0.85	0.27	564.6	25.71	0.17	Hashimoto, 1981
Beef cow/steer (high-energy diet)	398	5.44	0.34	564.6	25.71	0.33	Hashimoto, 1981
Broilers	1	15	1.1	N/A	N/A	0.36	Hill, 1984
Turkeys	7	9.7	0.74	N/A	N/A	0.36	Hill, 1984
Layers	2	10.25	0.79	N/A	N/A	0.39	Hill, 1982
Swine - Grow-Finish	61.25	5.4	0.42	N/A	N/A	0.48	Hashimoto, 1984
Swine - Farrow-to-Finish	61.25	5.4	0.42	N/A	N/A	0.48	Hashimoto, 1984

[a]USDA, 1996. Mature dairy characteristics are a combination of lactating and dry cow characteristics, assuming 17 percent of the herd is dry. Layer characteristics are a combination of layer and pullet characteristics. Swine farrow-to-finish characteristics are a combination of growing and breeding swine characteristics.
[b]Sweeten et al., 1997.
N/A - Not applicable.

operations. For some calculations, ERG estimates the amount of volatile solids or nitrogen entering specific waste management components. For example, under Option 5A (for beef feedlots, dairies, and heifer operations), ERG adjusted the amount of VS and TKN entering the compost pile, using available data from literature on the characteristics of animal waste (manure and bedding) entering the compost pile (Sweeten et al., 1997).

The methane-producing capacity of animal waste is related to the maximum volume of methane (m^3 CH_4) that can be produced per kilogram of VS, commonly referred to as B_o. Values for B_o are available from literature and are based on the type of animal and the animal diet.

Table 2.2-2 presents the runoff solids and manure composted data from the cost model methodology. ERG estimates the amount of runoff solids present at beef feedlots, dairies, and heifer operations and the amount of manure that is composted under Option 5A for these operations using the cost model methodology (U.S. EPA, 2002a).

The number of facilities and average head defined for each model farm, presented in Section 1.0 of this report, is also consistent with the cost model methodology used to estimate compliance costs for these operations.

2.2.2 Methane Emissions Methodology

Methane production is directly related to the quantity and quality of waste, the type of waste management system used, and the temperature and moisture of the waste (U.S. EPA, 1992). In general, manure that is handled under anaerobic conditions produces more methane, while manure that is handled in aerobic management systems produces little methane. Liquid and slurry systems typically have higher methane production because they often cause anaerobic conditions to develop. Certain animal populations, such as beef cattle on feedlots, have the potential to produce more methane because of higher energy diets that produce manure with a high methane-producing capacity.

Table 2.2-2

Data from the Cost Model Methodology Used in Greenhouse Gas Emission Calculations

Animal Type	Size Class	Runoff Solids (kg/yr)					Manure to Composting (tons/yr)				
		Central	Mid-Atlantic	Midwest	Pacific	South	Central	Mid-Atlantic	Midwest	Pacific	South
Beef	Large 2	2,242,228	7,256,052	3,776,384	7,839,369	8,628,363	44,200	41,437	43,355	41,115	40,681
	Large 1	159,225	515,267	268,169	556,690	612,718	3,139	2,943	3,079	2,920	2,889
	Medium 3	66,322	214,625	111,701	231,878	255,216	1,307	1,226	1,282	1,216	1,203
	Medium 2	47,794	154,664	80,494	167,098	183,915	942	883	924	876	867
	Medium 1	32,036	103,670	53,955	112,004	123,277	632	592	619	587	581
Heifer	Large 1	121,757	394,016	205,064	425,691	468,534	1,871	1,721	1,825	1,703	1,680
	Medium 3	71,025	229,842	119,621	248,320	273,312	1,091	1,004	1,064	993	980
	Medium 2	50,732	164,173	85,443	177,371	195,223	779	717	760	710	700
	Medium 1	32,468	105,071	54,684	113,518	124,943	499	459	487	454	448
Dairy	Large 1	111,432	360,603	187,674	389,592	428,803	4,595	4,595	4,595	4,595	4,595
	Medium 3	46,755	151,302	78,745	163,465	179,917	1,928	1,928	1,928	1,928	1,928
	Medium 2	33,118	107,172	55,777	115,788	127,441	1,366	1,366	1,366	1,366	1,366
	Medium 1	19,481	63,043	32,810	68,111	74,966	803	803	803	803	803

[a]U.S. EPA., 2002. Cost Methodology Report for Animal Feeding Operations. Washington DC. December.

Certain regulatory options evaluated for animal feeding operations are based on the use of different waste management systems that may increase or decrease methane emissions from animal operations. Methane is produced not only from animal waste, but also from the digestive processes of ruminant livestock due to enteric fermentation. However, because the regulatory options do not establish requirements dictating specific feeding strategies that affect diet, their effect on enteric fermentation methane emissions is difficult to predict and is not discussed in this report.

ERG calculates methane emissions using Equation 2-20, based on the methodology described in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000* (U.S. EPA, 2002b):

$$\text{Methane Emissions (per head)} = VS_{excreted} \times B_o \times 0.67\ \text{kg/m}^3 \times MCF \qquad [2\text{-}20]$$

where:

$VS_{excreted}$	=	Volatile solids excreted (kg/yr/head)
B_o	=	Maximum methane-producing capacity ($m^3\ CH_4$/kg VS)
MCF	=	Methane conversion factor based on the waste management system
0.67	=	Methane density at 20°C, 1 atmosphere (kg/m^3).

Each type of manure management component is assigned a methane conversion factor (MCF) to reflect the methane production potential for that system. MCFs for dry systems are set equal to default IPCC factors (IPCC, 2000), and are presented in Table 2.2-3.

However, the published default MCF for anaerobic lagoons is listed as 0 percent to 100 percent, which reflects the wide range in performance that may be achieved with these systems. There exist relatively few data points on which to determine MCFs for these systems. One practical way of estimating MCFs for liquid-manure-handling systems (i.e., liquid/slurry, deep-pit, and anaerobic lagoon systems) is based on the forecast performance of biological systems relative to temperature changes as predicted in the van’t Hoff-Arrhenius equation, using a base temperature of 30°C (Safley and Westerman, 1990), as shown in Equation 2-21.

Table 2.2-3

Methane Conversion Factors for Dry Waste Management System Components

Waste System Component	Methane Conversion Factor
Composting	0.01
Drylot	0.015
Poultry litter	0.015
Poultry without bedding	0.02
Stacked solids	0.01

$$f = \exp\left[\frac{E\ (T2 - T1)}{R\ T1\ T2}\right] \qquad [2\text{-}21]$$

where:

f	=	proportion of volatile solids that are biologically available for conversion to methane
T1	=	303.16 K
R	=	ideal gas constant (1.987 cal/K mol)
E	=	activation energy constant (15,175 cal/mol)
T2	=	ambient temperature for climate zone (for this analysis, average annual temperature for a geographic region is used).

The monthly generation of methane is calculated based on average monthly temperatures and the expected retention of volatile solids in the lagoon or liquid/slurry system from month to month. Monthly temperatures are calculated by using county-level temperature and population data. The weighted-average temperature for a state is calculated using animal population estimates and average monthly temperature in each county. For colder climates, a minimum temperature of 5°C was established for uncovered anaerobic lagoons and 7.5°C for other liquid-manure-handling systems (U.S. EPA, 2002b).

The monthly production of volatile solids that are added to the system is estimated based on the number of animals present and, for lagoon systems, adjusted for a management and design practices factor. This factor accounts for other mechanisms by which volatile solids are removed from the management system prior to conversion to methane, such as solids being removed from the system for application to cropland. This factor, equal to 0.8, has been estimated using currently available methane measurement data from anaerobic lagoon systems in the United States (ERG, 2001). The amount of volatile solids available for conversion to methane is assumed to be equal to the amount of volatile solids produced during the month. For anaerobic lagoons, the amount of volatile solids available also includes volatile solids that may remain in the system from previous months. The amount of volatile solids consumed during the month is equal to the amount available for conversion multiplied by the "*f*" factor. The amount of solids carried over from one month to the next in aerobic lagoons is equal to the amount available for conversion minus the amount consumed. The estimated amount of methane generated during the month is equal to the monthly volatile solids consumed multiplied by the maximum methane potential of the waste (B_o). The annual MCF is then calculated as shown in Equation 2-22:

$$\text{MCF (annual)} = \frac{CH_4 \text{ generated (annual)}}{\text{VS generated (annual)} \times B_o} \qquad [2\text{-}22]$$

To account for the carry-over volatile solids from the year prior to the inventory year for which estimates are calculated, it is assumed in the MCF calculation for lagoons that a portion of the volatile solids from October, November, and December of the year prior to the inventory year are available in the lagoon system starting January of the inventory year (U.S. EPA, 2002b).

Following this procedure, the resulting MCF (specific to an animal type and state) accounts for temperature variation throughout the year, residual volatile solids in a system (carry-over), and management and design practices that may reduce volatile solids available for conversion to methane. ERG then averaged the MCFs for each region of the country modeled. Table 2.2-4 presents the MCFs for liquid/slurry waste management system components for each animal type and region.

Table 2.2-4

Methane Conversion Factors for Liquid/Slurry Waste Management System Components by Region

Animal Type	Region	Liquid/Slurry Waste System Component		
		Anaerobic Lagoon[a]	Deep Pit	Waste Storage Pond
Beef	Central	N/A	N/A	0.29
	Mid-Atlantic	N/A	N/A	0.25
	Midwest	N/A	N/A	0.25
	Pacific	N/A	N/A	0.29
	South	N/A	N/A	0.40
Heifer	Central	N/A	N/A	0.28
	Mid-Atlantic	N/A	N/A	0.25
	Midwest	N/A	N/A	0.25
	Pacific	N/A	N/A	0.28
	South	N/A	N/A	0.40
Dairy	Central	0.70	N/A	N/A
	Mid-Atlantic	0.68	N/A	N/A
	Midwest	0.68	N/A	N/A
	Pacific	0.66	N/A	N/A
	South	0.76	N/A	N/A
Swine	Central	0.70	0.28	N/A
	Mid-Atlantic	0.69	0.26	N/A
	Midwest	0.69	0.25	N/A
	Pacific	0.67	0.28	N/A
	South	0.76	0.40	N/A
Wet Layers	Central	0.70	N/A	N/A
	Mid-Atlantic	0.68	N/A	N/A
	Midwest	0.69	N/A	N/A
	Pacific	0.66	N/A	N/A
	South	0.75	N/A	N/A

[a]Anaerobic digesters and covered anaerobic lagoons generate methane in the biogas. It is assumed that the methane generated is consumed when flared or combusted for energy recovery.
N/A- Not applicable.

2.2.3 Model Farm Methane Emissions

Using the methodology outlined above, emissions are calculated for each animal at a model farm in each region for each regulatory option (as defined in Section 1.0). This section presents the model farm emissions by animal type. Appendix B presents an example calculation.

<u>Beef/Heifer</u>

Based on the model farm definitions, all beef cattle on feedlots and heifers at heifer operations are housed in drylots; therefore, all wastes generated by these animals are deposited in the drylot and emit methane at the point of generation. Although a small fraction of beef feedlots and heifer operations may actually confine a small number of cattle in barns for all or part of the year, the waste is still deposited and handled as a solid material and is expected to emit similar amounts of methane. Additional methane is emitted when runoff from the drylot enters a waste storage pond. When a settling basin precedes the storage pond, the separated solids also generate methane when stacked.

For the baseline analysis, ERG assumes that all Large and 50 percent of Medium CAFOs have a waste storage pond in place. Using data provided by USDA, ERG further assumes the type of waste management systems currently in place at baseline at Large and Medium CAFOs that have "high," "medium," and "low" requirements. "High" requirements are assigned to 25 percent of the operations, "medium" requirements are assigned to 50 percent of the operations, and "low" requirements are assigned to 25 percent of the operations. The cost methodology report discusses these requirements in more detail (U.S. EPA, 2002a). Therefore, emissions are calculated for three types of manure management components: drylots, runoff ponds without solids separation, and runoff ponds with solids separation.

Table 2.2-5 presents the methane emission estimates by regulatory option and model farm for beef feedlots and heifer operations. Methane emissions at Large beef feedlots

Table 2.2-5

Methane Emissions for Beef Feedlots and Heifer Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Baseline	78,702	98,143	83,611	105,818	125,495
		Options 1-4, 6-7	74,047	85,156	76,852	89,541	100,786
		Option 5A	99,074	108,619	101,401	112,822	123,820
	Large 1	Baseline	5,588	6,969	5,937	7,514	8,911
		Options 1-4, 6-7	5,258	6,046	5,457	6,358	7,156
		Option 5A	7,035	7,713	7,200	8,011	8,792
Beef Medium CAFOs							
	Medium 3	Baseline	2,145	2,391	2,207	2,488	2,738
		Options 1-4, 6-7	2,191	2,519	2,274	2,649	2,982
		Option 5A	2,931	3,213	3,000	3,338	3,663
	Medium 2	Baseline	1,545	1,723	1,590	1,793	1,973
		Options 1-4, 6-7	1,578	1,815	1,638	1,908	2,148
		Option 5A	2,112	2,315	2,161	2,405	2,639
	Medium 1	Baseline	1,035	1,154	1,065	1,201	1,321
		Options 1-4, 6-7	1,057	1,215	1,097	1,278	1,439
		Option 5A	1,414	1,551	1,448	1,611	1,768
Heifer Large CAFOs							
	Large 1	Baseline	4,889	5,965	5,176	6,311	7,451
		Options 1-4, 6-7	4,645	5,260	4,809	5,458	6,109
		Option 5A	5,704	6,234	5,842	6,422	7,060
Heifer Medium CAFOs							
	Medium 3	Baseline	2,662	2,931	2,734	3,018	3,303
		Options 1-4, 6-7	2,710	3,068	2,805	3,184	3,563
		Option 4	3,328	3,637	3,408	3,746	4,118
	Medium 2	Baseline	1,902	2,094	1,953	2,155	2,359
		Options 1-4, 6-7	1,935	2,192	2,004	2,274	2,545
		Option 5A	2,377	2,598	2,434	2,676	2,942
	Medium 1	Baseline	1,217	1,340	1,250	1,379	1,510
		Options 1-4, 6-7	1,239	1,403	1,282	1,455	1,629
		Option 5A	1,521	1,662	1,558	1,713	1,883

and heifer operations decrease slightly from the baseline for all regulatory options except Option 5A. The emissions increase for all options for Medium CAFOs.

Options 1 through 4, 6, and 7 are based on all operations adding a solids separation basin followed by a waste storage pond to control runoff (if they do not currently operate them). For Large operations, baseline assumes all operations have a pond, and the options add a solids separation basin. Removing more manure waste from the liquid waste storage pond decreases methane emissions. For Medium CAFOs, baseline assumes that not all operations have a pond or basin; therefore, adding a pond results in more waste (i.e., runoff) being contained on site and contributing to methane emissions.

Option 5A is based upon all operations composting their manure waste, which generates more methane than liquid storage. More methane would be emitted from compost piles as the compost piles are turned than from stacked solids.

Dairy

The dairy model farm assumes that mature dairy cattle are housed in confinement barns and milked in milking parlors, while heifers and calves are housed in drylots. All dairies generate methane from calves and heifers as the manure is deposited in the drylot. As with beef feedlots, methane emissions occur from drylot runoff. For this analysis, ERG assumes that a certain portion of the industry flush the confinement barns and parlors, and the rest scrape the barns and hose the parlor. Dairies generate methane from the anaerobic lagoons used to store the liquid waste from flushing and hose operations and drylot runoff. In addition, when runoff is sent to a concrete settling basin before being stored in an anaerobic lagoon, the separated solids also generate methane. Scrape dairies also generate methane at the point of generation in the barn.

For the baseline analysis, ERG assumes that all Large dairies and 90 percent of Medium dairy CAFOs have an anaerobic lagoon in place to store liquid waste. Using data provided by USDA, ERG further assumes the type of waste management systems currently in place at baseline at Large and Medium CAFOs that have “high,” “medium,” and “low” requirements. “High” requirements are assigned to 25 percent of the operations, “medium” requirements are assigned to 50 percent of the operations, and “low” requirements are assigned to 25 percent of the operations. The cost methodology report discusses these requirements in more detail (U.S. EPA, 2002a). Therefore, emissions are calculated for three types of manure management components: drylots, anaerobic lagoons without solids separation, and anaerobic lagoons with solids separation. The total methane emissions generated by each type of dairy animal is represented by the following equations:

$$CH_4\ \text{Emissions}_{\text{dairy calf/heifer}} = \text{Drylot} + \text{Anaerobic Lagoon}_{\text{runoff}}$$

$$CH_4\ \text{Emissions}_{\text{mature-scrape}} = \text{Stacked Solids}_{\text{barn}} + \text{Separated Solids}_{\text{parlor}} + \text{Anaerobic Lagoon}_{\text{parlor}}$$

$$CH_4\ \text{Emissions}_{\text{mature-flush}} = \text{Separated Solids}_{\text{barn+parlor}} + \text{Anaerobic Lagoon}_{\text{barn+parlor}}$$

Table 2.2-6 presents the methane emission estimates in each region by regulatory option and model farm for dairy flush and scrape operations. Methane emissions at Large dairies decrease under all regulatory options, markedly so under Option 6. Option 6 is based on Large dairies installing a digester with energy recovery. Virtually all methane generated in the digester is destroyed.

Options 1 through 4 and 7 are based on all dairies adding a solids separation basin followed by an anaerobic lagoon (if they do not currently operate them). For Large dairies, baseline assumes all operations have a lagoon, and under all options they add a concrete settling basin. For Medium CAFOs, baseline assumes that not all operations have a lagoon or basin. Removing more manure waste from the liquid lagoon decreases methane emissions.

Option 5A is based on all operations composting their manure waste, which would generate slightly more methane compared to Options 1 through 4 and 7; however, implementation of Option 5A would result in an overall decrease to methane emissions compared to baseline.

Table 2.2-6

Methane Emissions for Dairies by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Dairy - Flush Large CAFOs							
	Large 1	Baseline	256,084	250,327	249,277	243,183	280,048
		Options 1-4, 7	156,458	153,610	152,560	149,375	171,697
		Option 5A	159,060	156,212	155,161	151,977	174,298
		Option 6	3,818	3,835	3,823	3,837	3,839
Dairy - Flush Medium CAFOs							
	Medium 3	Baseline	102,779	100,429	100,032	97,554	112,359
		Options 1-4, 7	65,648	64,453	64,012	62,676	72,042
		Option 5A	66,739	65,544	65,104	63,767	73,133
		Option 6	65,648	64,453	64,012	62,676	72,042
	Medium 2	Baseline	72,852	71,186	70,905	69,148	79,642
		Options 1-4, 7	46,532	45,685	45,373	44,426	51,064
		Option 5A	47,306	46,458	46,146	45,199	51,837
		Option 6	46,532	45,685	45,373	44,426	51,064
	Medium 1	Baseline	42,892	41,911	41,745	40,711	46,889
		Options 1-4, 7	27,396	26,897	26,713	26,155	30,064
		Option 5A	27,851	27,352	27,168	26,610	30,519
		Option 6	27,396	26,897	26,713	26,155	30,064
Dairy - Scrape Large CAFOs							
	Large 1	Baseline	45,011	45,417	44,367	44,436	50,488
		Options 1-4, 7	30,068	30,910	29,860	30,365	34,236
		Option 5A	32,669	33,512	32,461	32,967	36,837
		Option 6	6,586	6,602	6,591	6,604	6,607
Dairy - Scrape Medium CAFOs							
	Medium 3	Baseline	18,190	18,380	17,939	17,987	20,431
		Options 1-4, 7	12,616	12,969	12,529	12,741	14,365
		Option 5A	13,708	14,061	13,620	13,832	15,456
		Option 6	12,616	12,969	12,529	12,741	14,365
	Medium 2	Baseline	12,893	13,027	12,715	12,749	14,481
		Options 1-4, 7	8,942	9,193	8,880	9,031	10,181
		Option 5A	9,716	9,966	9,654	9,804	10,955
		Option 6	8,942	9,193	8,880	9,031	10,181
	Medium 1	Baseline	7,591	7,670	7,486	7,506	8,525
		Options 1-4, 7	5,265	5,412	5,228	5,316	5,994
		Option 5A	5,720	5,867	5,683	5,771	6,449
		Option 6	5,265	5,412	5,228	5,316	5,994

Veal

The veal model farm assumes all calves are housed in confinement barns. A certain portion of the industry flushes the confinement barns and stores the manure waste in an anaerobic lagoon; the rest of the industry has barns with underpit storage for the manure. For this analysis, ERG assumes that 67 percent of all veal operations have a lagoon, 33 percent have underpit storage, and all operations equipped with a lagoon also have a settling basin in place. Methane is emitted from the lagoon, separated solids, and solids from underpit storage; therefore, the total methane emissions generated by each type of veal operation is represented by the following equations:

$$CH_4\ Emissions_{underpit\ storage} = Stacked\ Solids_{pit}$$

$$CH_4\ Emissions_{flush} = Separated\ Solids_{barn} + Anaerobic\ Lagoon_{barn}$$

Table 2.2-7 presents the methane emission estimates by regulatory option and model farm for veal flush and underpit storage operations. No changes are expected in emissions for veal operations equipped with underpit storage under any regulatory option. Flush operations have a decrease in emissions under Option 5, because under this options, anaerobic lagoons are covered and the biogas generated is flared.

Table 2.2-7

Methane Emissions for Veal Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Veal - Flush Medium CAFOs							
	Medium 3	Baseline and Options 1-4, 6-7	3,752	3,647	3,647	3,542	4,067
		Option 5	79	79	79	79	79
	Medium 2	Baseline and Options 1-4, 6-7	1,876	1,824	1,824	1,771	2,033
		Option 5	39	39	39	39	39
	Medium 1	Baseline and Options 1-4, 6-7	1,390	1,351	1,351	1,312	1,506
		Option 5	29	29	29	29	29
Veal - Underpit Storage Medium CAFOs							
	Medium 3	Baseline and all options	3,149	2,624	2,624	2,939	4,198
	Medium 2	Baseline and all options	1,574	1,312	1,312	1,469	2,099
	Medium 1	Baseline and all options	1,166	972	972	1,088	1,555

Poultry

The model farm for broilers and turkeys assumes all animals are housed in poultry houses using a litter-based system. Methane is generated from the manure as it is “stored” on the floor of the house.

The model farm for dry layer operations assumes all animals are housed in poultry houses with suspended cages over the floor. Methane is generated from the manure as it is “stored” on the floor of the house. The model farm for wet layer operations assumes the waste is flushed from the house and stored in an anaerobic lagoon. As with other animal groups discussed above, methane is emitted from the lagoon.

Table 2.2-8 presents the methane emission estimates in each region by regulatory option and model farm for poultry operations. No changes are expected in emissions from broiler, turkey, and dry layer operations under any regulatory option. Option 5 is based on wet layer operations having covered lagoons. Emissions are negligible under this option because operations are expected to flare the biogas.

Table 2.2-8

Methane Emissions for Poultry Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region		
			Mid-Atlantic	Midwest	South
Broilers Large CAFOs					
	Large 2	Baseline and all Regulatory Options	6,661	N/A	6,705
	Large 1		2,135	N/A	2,115
Broilers Medium CAFOs					
	Medium 3	Baseline and all Regulatory Options	1,440	N/A	1,444
	Medium 2		920	N/A	916
	Medium 1		699	N/A	696
Turkey Large CAFOs					
	Large 1	Baseline and all Regulatory Options	11,553	11,553	N/A
Turkey Medium CAFOs					
	Medium 3	Baseline and all Regulatory Options	3,948	3,948	N/A
	Medium 2		2,693	2,693	N/A
	Medium 1		1,597	1,597	N/A
Layers - Dry Large CAFOs					
	Large 2	Baseline and all Regulatory Options	N/A	29,722	29,722
	Large 1		N/A	6,228	6,228
Layers - Dry Medium CAFOs					
	Medium 3	Baseline and all Regulatory Options	N/A	2,236	2,236
	Medium 2		N/A	1,296	1,296
	Medium 1		N/A	873	873
Layers Wet - Large CAFOs					
	Large 1	Baseline and Options 1-4, 6-7	N/A	N/A	114,683
		Option 5[a]	N/A	N/A	114,683
Layers Wet - Medium CAFOs					
	Medium 3	Baseline and Options 1-4, 6-7	N/A	N/A	4,822
		Option 5[a]	N/A	N/A	4,822

N/A - Not Applicable.
[a]Assumes all biogas is collected and flared; methane emissions are negligible.

Swine

The model farm for swine operations assumes all swine are housed in total confinement barns. Swine operations generate methane from the anaerobic lagoons, deep pits, and evaporative lagoons used to store liquid slurry waste. For this analysis, ERG assumes that Mid-Atlantic and Midwest swine operations flush manure to an aerobic lagoon or store the manure in deep pits. ERG also assumes that all Central swine operations flush the manure to evaporative lagoons.

Table 2.2-9 presents the methane emission estimates by regulatory option and model farm for swine operations. Flush operations with anaerobic lagoons in the Mid-Atlantic and Midwest are expected to decrease emissions under Option 5 because this option is based on covered anaerobic lagoons and flaring the generated biogas. The Large swine operations are expected to decrease emissions under Option 6 because this option is based on collecting the biogas for energy recovery. For both of these cases, methane emissions are expected to be negligible.

Table 2.2-9

Methane Emissions for Swine Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region: Central	Region: Mid-Atlantic	Region: Midwest
Swine - Grow-Finish - Lagoon and Evaporative Lagoon Large CAFOs					
	Large 2	Baseline and Options 1-4, and 7	798,715	238,235	268,668
		Option 5[a]	0	0	0
		Option 6[a]	0	0	0
	Large 1	Baseline and Options 1-4, and 7	93,898	95,208	91,538
		Option 5[a]	0	0	0
		Option 6[a]	0	0	0
Swine - Grow-Finish - Lagoon and Evaporative Lagoon Medium CAFOs					
	Medium 3	Baseline and Options 1-4, and 7	N/A	58,507	56,900
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	58,507	56,900
	Medium 2	Baseline and Options 1-4, and 7	N/A	40,746	38,094
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	40,746	38,094
	Medium 1	Baseline and Options 1-4, and 7	N/A	25,798	24,110
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	25,798	24,110
Swine - Grow-Finish - Deep Pit Large CAFOs					
	Large 2	Baseline and Options 1-4, and 7	319,486	89,770	97,343
		Option 5[a]	319,486	89,770	97,343
		Option 6[a]	0	0	0
	Large 1	Baseline and Options 1-4, and 7	37,559	35,876	33,166
		Option 5[a]	37,559	35,876	33,166
		Option 6[a]	0	0	0

Table 2.2-9 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Region: Mid-Atlantic	Region: Midwest
Swine - Grow Finish - Deep Pit Medium CAFOs					
	Medium 3	Baseline and Options 1-4, and 7	N/A	22,046	20,616
		Option 5[a]	N/A	22,046	20,616
		Option 6[a]	N/A	22,046	20,616
	Medium 2	Baseline and Options 1-4, and 7	N/A	15,354	13,802
		Option 5[a]	N/A	15,354	13,802
		Option 6[a]	N/A	15,354	13,802
	Medium 1	Baseline and Options 1-4, and 7	N/A	9,721	8,736
		Option 5[a]	N/A	9,721	8,736
		Option 6[a]	N/A	9,721	8,736
Swine - Farrow-to-Finish - Lagoon and Evaporative Lagoon Large CAFOs					
	Large 2	Baseline and Options 1-4, and 7	225,517	451,930	370,198
		Option 5[a]	0	0	0
		Option 6[a]	0	0	0
	Large 1	Baseline and Options 1-4, and 7	98,545	92,641	92,262
		Option 5[a]	0	0	0
		Option 6[a]	0	0	0
Swine - Farrow-to-Finish - Lagoon and Evaporative Lagoon Medium CAFOs					
	Medium 3	Baseline and Options 1-4, and 7	N/A	57,158	57,650
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	57,158	57,650
	Medium 2	Baseline and Options 1-4, and 7	N/A	40,076	39,112
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	40,076	39,112
	Medium 1	Baseline and Options 1-4, and 7	N/A	22,335	21,806
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	22,335	21,806

Table 2.2-9 (Continued)

Animal Type	Size Class	Regulatory Option	Region		
			Central	Mid-Atlantic	Midwest
Swine - Farrow-to-Finish - Deep Pit Large CAFOs					
	Large 2	Baseline and Options 1-4, and 7	90,207	172,797	134,130
		Option 5[a]	90,207	172,797	134,130
		Option 6[a]	0	0	0
	Large 1	Baseline and Options 1-4, and 7	39,418	35,421	33,428
		Option 5[a]	39,418	35,421	33,428
		Option 6[a]	0	0	0
Swine - Farrow-to-Finish - Deep Pit Medium CAFOs					
	Medium 3	Baseline and Options 1-4, and 7	N/A	21,854	20,888
		Option 5[a]	N/A	21,854	20,888
		Option 6[a]	N/A	21,854	20,888
	Medium 2	Baseline and Options 1-4, and 7	N/A	15,323	14,171
		Option 5[a]	N/A	15,323	14,171
		Option 6[a]	N/A	15,323	14,171
	Medium 1	Baseline and Options 1-4, and 7	N/A	8,540	7,901
		Option 5[a]	N/A	8,540	7,901
		Option 6[a]	N/A	8,540	7,901

N/A - Not Applicable.
[a]Assumes all biogas is collected and flared. It is assumed that methane emissions are negligible.

2.2.4 Nitrous Oxide Methodology

Nitrous oxide is produced as part of the nitrogen cycle through the nitrification and denitrification of the organic nitrogen in livestock manure and urine. The emission of nitrous oxide from manure management systems is based on the nitrogen content of the manure, as well as the length of time the manure is stored and the specific type of system used. In general, the amount of nitrous oxide emitted from manure management systems tends to be small because conditions are often not suitable for nitrification to occur; however, when nitrous oxide is generated, manure that is handled as a liquid tends to produce less nitrous oxide than manure that is handled as a solid. Certain regulatory options evaluated for animal feeding operations are based on the use of different waste management systems that may increase nitrous oxide emissions from animal operations.

The amount of nitrous oxide produced is related to the amount of nitrogen excreted by the animal. Values for TKN, a measure of organic nitrogen plus ammonia nitrogen, are typically available for animal waste. ERG calculates nitrous oxide emissions using Equation 2-23, based on the methodology described in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000* (U.S. EPA, 2002b).

$$N_2O \text{ Emissions (per head)} = N_{excreted} \times EF \times \frac{44\ N_2O}{28\ N} \qquad [2\text{-}23]$$

where:

$N_{excreted}$ = TKN (kg/yr/head)
EF = N_2O emission factor based on the management system (kg N_2O-N/kg N)
44/28 = conversion factor to N_2O.

Table 2.2-11 presents the default nitrogen emission factors for waste management system components (IPCC, 2000). These emission factors do not vary based on region. As shown in Table 2.2-10, the emission factors for liquid-handling systems (e.g., anaerobic lagoons, waste storage pond) are an order of magnitude less than those for dry systems (e.g., composting, drylot, stacked solids).

2.2.5 Model Farm Nitrous Oxide Emissions

Using the methodology outlined above, emissions are calculated for each animal at a model farm in each region for each regulatory option (as defined in Section 1.0). This section presents the model farm emissions by animal type. Appendix B presents an example calculation. The same model farm assumptions outlined in Section 2.2.3 (methane emissions) are used to calculate the nitrous oxide emissions.

Table 2.2-10

Nitrous Oxide Emission Factors

Waste System Component	Emission Factor
Aerobic treatment (e.g., hog high-rise house)	0.02
Anaerobic lagoon	0.001
Anaerobic digester	[a]
Composting	0.02
Deep pit	0.001
Drylot	0.02
Poultry litter	0.02
Poultry without bedding	0.005
Stacked solids	0.02
Waste storage pond	0.001

[a]Assumes all biogas is collected and flared; nitrous oxide emissions are negligible.

<u>Beef/Heifer</u>

Table 2.2-11 presents the nitrous oxide emission estimates by regulatory option and model farm for beef feedlots and heifer operations. Nitrous oxide emissions at Large beef feedlots and heifer operations decrease slightly from the baseline for all regulatory options except Option 5A. The emissions increase slightly for all options for Medium CAFOs.

Options 1 through 4, 6, and 7 assume that all operations add a solids separation basin followed by a waste storage pond to control runoff (if they do not currently operate them). For Large operations, baseline assumes all operations have a pond and would add a solids separation basin under all options. Removing more manure waste from the liquid waste storage pond decreases nitrous oxide emissions. For Medium CAFOs, baseline assumes that not all operations have a pond or basin; therefore, adding a pond results in more waste (i.e., runoff) contained on site and contributes to nitrous oxide emissions.

Option 5A is based on all operations composting their manure waste, which would generate more nitrous oxide than liquid storage. More nitrous oxide is emitted from compost piles as the compost piles are turned than from stacked solids.

Table 2.2-11

Nitrous Oxide Emissions for Beef Feedlots and Heifer Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Baseline	40,196	40,234	40,208	40,238	40,244
		Options 1-4, 6-7	40,189	40,210	40,196	40,213	40,216
		Option 5A	56,389	40,970	40,990	40,966	40,962
	Large 1	Baseline	2,854	2,857	2,855	2,857	2,857
		Options 1-4, 6-7	2,854	2,855	2,854	2,855	2,855
		Option 5A	2,911	2,909	2,910	2,909	2,908
Beef Medium CAFOs							
	Medium 3	Baseline	1,189	1,189	1,189	1,189	1,190
		Options 1-4, 6-7	1,189	1,190	1,189	1,190	1,190
		Option 5A	1,213	1,212	1,213	1,212	1,212
	Medium 2	Baseline	857	857	857	857	857
		Options 1-4, 6-7	857	857	857	857	857
		Option 5A	874	873	874	873	873
	Medium 1	Baseline	573	574	574	574	574
		Options 1-4, 6-7	573	574	574	574	574
		Option 5A	585	585	585	585	585
Heifer Large CAFOs							
	Large 1	Baseline	1,634	1,636	1,635	1,636	1,636
		Options 1-4, 6-7	1,634	1,635	1,634	1,635	1,635
		Option 5A	2,319	2,265	2,303	2,259	2,251
Heifer Medium CAFOs							
	Medium 3	Baseline	953	953	953	953	953
		Options 1-4, 6-7	953	954	953	954	954
		Option 4	1,353	1,321	1,343	1,318	1,313
	Medium 2	Baseline	681	681	681	681	681
		Options 1-4, 6-7	681	681	681	681	681
		Option 5A	966	944	959	941	938
	Medium 1	Baseline	436	436	436	436	436
		Options 1-4, 6-7	436	436	436	436	436
		Option 5A	618	604	614	602	600

Dairy

Table 2.2-12 presents the nitrous oxide emission estimates by regulatory option and model farm for flush and scrape dairies. Nitrous oxide emissions at Large dairies increase under all regulatory options. Options 1 through 4 and 7 assume that all operations add a solids separation basin followed by an anaerobic lagoon (if they do not currently operate them). For Large dairies, baseline assumes all operations have a lagoon and would add a concrete settling basin under all options. For Medium dairy CAFOs, baseline assumes that not all operations have a lagoon or basin. Removing more manure waste from the liquid lagoon increases nitrous oxide emissions.

Under Option 5A, ERG assumes that all lagoons are covered and biogas from the covered lagoon is flared. Consequently, implementation of Option 5A would generate more nitrous oxide compared to Options 1 through 4, 6, and 7. Option 6 is based on Large dairies installing a digester with energy recovery. Virtually all nitrous oxide generated in a digester is destroyed.

Veal

Table 2.2-13 presents the nitrous oxide emission estimates by regulatory option and model farm for veal flush and underpit storage operations. No changes are expected in emissions from veal operations equipped with underpit storage under any regulatory option. Flush operations have a decrease in emissions under Option 5 because this option is based on covered anaerobic lagoons and flaring the biogas generated.

Table 2.2-12

Nitrous Oxide Emissions for Dairy Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Dairy - Flush Large CAFOs							
	Large 1	Baseline	1,526	1,528	1,527	1,528	1,529
		Options 1-4, 7	2,965	2,966	2,965	2,967	2,967
		Option 5A	5,082	5,024	5,072	5,018	4,988
		Option 6	2,852	2,853	2,852	2,854	2,854
Dairy - Flush Medium CAFOs							
	Medium 3	Baseline	514	515	514	515	515
		Options 1-4, 7	1,244	1,245	1,244	1,245	1,245
		Option 5A	1,930	1,912	1,927	1,910	1,900
		Option 6	1,244	1,245	1,244	1,245	1,245
	Medium 2	Baseline	364	365	364	365	365
		Options 1-4, 7	882	882	882	882	882
		Option 5A	1,568	1,549	1,565	1,547	1,537
		Option 6	882	882	882	882	882
	Medium 1	Baseline	214	215	215	215	215
		Options 1-4, 7	481	482	482	482	482
		Option 5A	832	822	830	822	817
		Option 6	481	482	482	482	482
Dairy - Scrape Large CAFOs							
	Large 1	Baseline	4,573	4,575	4,574	4,575	4,576
		Options 1-4, 7	4,789	4,791	4,790	4,791	4,791
		Option 5A	6,906	6,848	6,897	6,843	6,812
		Option 6	4,772	4,774	4,773	4,774	4,774
Dairy - Scrape Medium CAFOs							
	Medium 3	Baseline	1,900	1,901	1,900	1,901	1,901
		Options 1-4, 7	2,009	2,010	2,010	2,010	2,010
		Option 5A	2,696	2,677	2,693	2,675	2,665
		Option 6	2,009	2,010	2,010	2,010	2,010
	Medium 2	Baseline	1,347	1,347	1,347	1,347	1,347
		Options 1-4, 7	1,424	1,425	1,424	1,425	1,425
		Option 5A	2,111	2,092	2,108	2,090	2,080
		Option 6	1,424	1,425	1424	1,425	1,425
	Medium 1	Baseline	796	796	796	796	797
		Options 1-4, 7	556	557	556	557	557
		Option 5A	907	897	905	896	891
		Option 6	556	557	556	557	557

Table 2.2-13

Nitrous Oxide Emissions for Veal Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Veal - Flush Medium CAFOs							
	Medium 3	Baseline and Options 1-4, 6-7	3,752	3,647	3,647	3,542	4,067
		Option 5	79	79	79	79	79
	Medium 2	Baseline and Options 1-4, 6-7	1,876	1,824	1,824	1,771	2,033
		Option 5	39	39	39	39	39
	Medium 1	Baseline and Options 1-4, 6-7	1,390	1,351	1,351	1,312	1,506
		Option 5	29	29	29	29	29
Veal - Underpit Storage Medium CAFOs							
	Medium 3	Baseline and all options	3,149	2,624	2,624	2,939	4,198
	Medium 2	Baseline and all options	1,574	1,312	1,312	1,469	2,099
	Medium 1	Baseline and all options	1,166	972	972	1,088	1,555

Poultry

Table 2.2-14 presents the nitrous oxide emission estimates by regulatory option and model farm for poultry operations. There are no changes expected to emissions from broiler, turkey, and dry layer operations under any regulatory option. Option 5 is based on wet layer operations with covered lagoons. Emissions are negligible under this option because operations are expected to flare the biogas.

Swine

Table 2.2-15 presents the nitrous oxide emission estimates by regulatory option and model farm for swine operations. Flush operations with anaerobic lagoons in the Mid-Atlantic and Midwest regions are expected to have a decrease in emissions under Option 5 because this option is based on covered anaerobic lagoons and flaring the generated biogas. Large swine operations are expected to have a decrease in emissions under Option 6 because this option is based on digesters collecting the biogas for energy recovery. For both of these cases, nitrous oxide emissions are expected to be negligible.

Table 2.2-14

Nitrous Oxide Emissions for Poultry Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region: Mid-Atlantic	Region: Midwest	Region: South
Broilers Large CAFOs					
	Large 2	Baseline and all options	4,243	N/A	4,271
	Large 1		1,360	N/A	1,347
Broilers Medium CAFOs					
	Medium 3	Baseline and all options	917	N/A	920
	Medium 2		586	N/A	584
	Medium 1		445	N/A	443
Turkey Large CAFOs					
	Large 1	Baseline and all options	7,656	7,656	N/A
Turkey Medium CAFOs					
	Medium 3	Baseline and all options	2,616	2,616	N/A
	Medium 2		1,785	1,785	N/A
	Medium 1		1,058	1,058	N/A
Layers - Dry Large CAFOs					
	Large 2	Baseline and all options	N/A	4,592	4,592
	Large 1		N/A	962	962
Layers - Dry Medium CAFOs					
	Medium 3	Baseline and all options	N/A	345	345
	Medium 2		N/A	200	200
	Medium 1		N/A	135	135
Layers - Wet Large CAFOs					
	Large 1	Baseline and options 1-4, 6-7	N/A	N/A	71
		Option 5[a]	N/A	N/A	71
Layers - Wet Medium CAFOs					
	Medium 3	Baseline and options 1-4, 6-7	N/A	N/A	3
		Option 5[a]	N/A	N/A	3

N/A - Not applicable.
[a]Assumes all biogas is collected and flared; nitrous oxide emissions are negligible.

Table 2.2-15

Nitrous Oxide Emissions for Swine Operations by Regulatory Option and Model Farm (kg/yr)

Animal Type	Size Class	Regulatory Option	Region		
			Central	Mid-Atlantic	Midwest
Swine - Grow Finish - Lagoon and Evaporative Lagoon Large CAFOs					
	Large 2	Baseline and Options 1-4, and 7	434	131	71
		Option 5[a]	0	0	0
		Option 6[a]	0	0	0
	Large 1	Baseline and Options 1-4, and 7	51	52	24
		Option 5[a]	0	0	0
		Option 6[a]	0	0	0
Swine - Grow Finish - Lagoon and Evaporative Lagoon Medium CAFOs					
	Medium 3	Baseline and Options 1-4, and 7	N/A	32	15
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	32	15
	Medium 2	Baseline and Options 1-4, and 7	N/A	22	10
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	22	10
	Medium 1	Baseline and Options 1-4, and 7	N/A	14	6
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	14	6
Swine - Grow Finish - Deep-Pit Large CAFOs					
	Large 2	Baseline and Options 1-4, and 7	434	131	71
		Option 5[a]	434	131	71
		Option 6[a]	0	0	0
	Large 1	Baseline and Options 1-4, and 7	51	52	24
		Option 5[a]	51	52	24
		Option 6[a]	0	0	0

Table 2.2-15 (Continued)

Animal Type	Size Class	Regulatory Option	Region		
			Central	Mid-Atlantic	Midwest
Swine - Grow Finish - Deep-Pit Medium CAFOs					
	Medium 3	Baseline and Options 1-4, and 7	N/A	32	15
		Option 5[a]	N/A	32	15
		Option 6[a]	N/A	32	15
	Medium 2	Baseline and Options 1-4, and 7	N/A	22	10
		Option 5[a]	N/A	22	10
		Option 6[a]	N/A	22	10
	Medium 1	Baseline and Options 1-4, and 7	N/A	14	6
		Option 5[a]0	N/A	14	6
		Option 6[a]	N/A	14	6
Swine - Farrow-to-Finish - Lagoon and Evaporative Lagoon Large CAFOs					
	Large 2	Baseline and Options 1-4, and 7	122	253	98
		Option 5[a]	0	0	0
		Option 6[a]	0	0	0
	Large 1	Baseline and Options 1-4, and 7	54	52	24
		Option 5[a]	0	0	0
		Option 6[a]	0	0	0
Swine - Farrow-to-Finish - Lagoon and Evaporative Lagoon Medium CAFOs					
	Medium 3	Baseline and Options 1-4, and 7	N/A	32	15
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	32	15
	Medium 2	Baseline and Options 1-4, and 7	N/A	22	10
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	22	10
	Medium 1	Baseline and Options 1-4, and 7	N/A	12	6
		Option 5[a]	N/A	0	0
		Option 6[a]	N/A	12	6

Table 2.2-15 (Continued)

Animal Type	Size Class	Regulatory Option	Region		
			Central	Mid-Atlantic	Midwest
Swine - Farrow-to-Finish - Deep-Pit Large CAFOs					
	Large 2	Baseline and Options 1-4, and 7	122	253	98
		Option 5[a]	122	253	98
		Option 6[a]	0	0	0
	Large 1	Baseline and Options 1-4, and 7	54	52	24
		Option 5[a]	54	52	24
		Option 6[a]	0	0	0
Swine - Farrow-to-Finish - Deep-Pit Medium CAFOs					
	Medium 3	Baseline and Options 1-4, and 7	N/A	32	15
		Option 5[a]	N/A	32	15
		Option 6[a]	N/A	32	15
	Medium 2	Baseline and Options 1-4, and 7	N/A	22	10
		Option 5[a]	N/A	22	10
		Option 6[a]	N/A	22	10
	Medium 1	Baseline and Options 1-4, and 7	N/A	12	6
		Option 5[a]	N/A	12	6
		Option 6[a]	N/A	12	6

N/A - Not Applicable.
[a] Assumes all biogas is collected and flared; nitrous oxide emissions are negligible.

2.3 Criteria Air Emissions from Energy Recovery Systems

Criteria air pollutants are those pollutants for which a national ambient air quality standard has been set. The criteria pollutants evaluated as non-water quality impacts from energy recovery systems include oxides of nitrogen (NO_x), which are precursors to ozone, as well as sulfur dioxide (SO_2), and carbon monoxide (CO). These criteria pollutants are formed during the flaring and combustion of biogas. Particulate matter (PM) and volatile organic compounds (VOCs) were not included in this analysis. A properly operated flare or gas turbine should have minimal or no VOC emissions. Sulfur dioxide was calculated here despite not being included in the transportation and composting analyses; sulfur dioxide is formed when biogas is combusted or flared but is not a significant by-product of transportation or composting activities.

2.3.1 Data Inputs

The estimation of criteria air emissions from energy recovery systems is based on one primary data input: the amount of methane generated from the anaerobic lagoon or digester systems. This value is used to estimate the amount of biogas generated at the model farm. Table 2.3-1 presents the estimate of total methane generated at each model farm for Options 5 and 6 based on the methodology discussed in Section 2.2.

2.3.2 Emissions Methodology

Criteria pollutant air emissions from flaring and energy recovery systems are expected under Options 5 and 6. Under Option 5, anaerobic lagoons at all swine, chicken, and veal CAFOs are expected to be covered and the biogas vented to a flare. Option 6 is based on the implementation of anaerobic digestion systems with energy recovery for all Large dairy and swine CAFOs. Options 5 and 6 are expected to greatly reduce the emissions of methane through the capture of the biogas; however, flaring the biogas or using it in an energy recovery system will increase emissions of the criteria pollutants NO_x, SO_2, and CO. These pollutants are generated from oxidation of nitrogen (from NH_3), sulfur (from H_2S), and carbon compounds (from organics and methane).

Table 2.3-1

Total Methane Generated - Options 5 and 6 (kg/year)

Animal Type	Size Class	System Type	Units	Central	Mid-Atlantic	Midwest	Pacific	South
Option 5								
Veal	Medium 3	Flush	kgCH4/year	3,673	3,568	3,568	3,463	3,988
	Medium 2	Flush	kgCH4/year	1,837	1,784	1,784	1,732	1,994
	Medium 1	Flush	kgCH4/year	1,360	1,322	1,322	1,283	1,477
Swine	Large 2	Farrow-to-Finish	kgCH4/year	225,517	451,930	370,198	N/A	N/A
	Large 1	Farrow-to-Finish	kgCH4/year	98,545	92,641	92,262	N/A	N/A
	Medium 3	Farrow-to-Finish	kgCH4/year	N/A	57,158	57,650	N/A	N/A
	Medium 2	Farrow-to-Finish	kgCH4/year	N/A	40,076	39,112	N/A	N/A
	Medium 1	Farrow-to-Finish	kgCH4/year	N/A	22,335	21,806	N/A	N/A
Swine	Large 2	Grow-Finish	kgCH4/year	798,715	238,235	268,668	N/A	N/A
	Large 1	Grow-Finish	kgCH4/year	93,898	95,208	91,538	N/A	N/A
	Medium 3	Grow-Finish	kgCH4/year	N/A	58,507	56,900	N/A	N/A
	Medium 2	Grow-Finish	kgCH4/year	N/A	40,746	38,094	N/A	N/A
	Medium 1	Grow-Finish	kgCH4/year	N/A	25,798	24,110	N/A	N/A
Wet Layer	Large 1	Flush	kgCH4/year	N/A	N/A	N/A	N/A	114,683
	Medium 3	Flush	kgCH4/year	N/A	N/A	N/A	N/A	4,822
Option 6								
Dairy	Large 1	Flush	kgCH4/year	152,648	149,800	148,749	145,565	167,886
		Hose	kgCH4/year	23,489	24,332	23,281	23,787	27,657
Swine	Large 2	Farrow-to-Finish	kgCH4/year	225,517	451,930	370,198	N/A	N/A
		Grow-Finish	kgCH4/year	798,715	238,235	268,668	N/A	N/A
	Large 1	Farrow-to-Finish	kgCH4/year	98,545	92,641	92,262	N/A	N/A
		Grow-Finish	kgCH4/year	93,898	95,208	91,538	N/A	N/A

N/A- Not applicable.

Calculation of Biogas Volume

The methodologies used to estimate the emissions of these pollutants require information on the volume of the biogas being burned. It is assumed that the biogas consists of approximately 70 percent methane and 30 percent carbon dioxide by volume. ERG calculated a total volume of biogas from the methane mass values presented in Table 2.3-1 by converting to a volumetric flow basis using the ideal gas law at standard temperature and pressure, as shown in Equation 2.24. These methodologies were developed in consultation with EPA's Office of Air Quality Planning and Standards (OAQPS).

$$PV = nRT \qquad [2\text{-}24]$$

where:

P	=	pressure = 1.01325×10^5 Pa
R	=	gas law constant = 8.314 ($m^3 \times$ Pa)/ (mol $\times$ K)
T	=	temperature = 293 K
n	=	moles of gas = $(m_{CH4}/MW_{CH4}) \times 1000$
m_{CH4}	=	methane mass generation value from OW calculation (kg/yr)
MW_{CH4}	=	methane molecular weight = 16 g/mol.

Total volume of biogas (V_{bio}) generated and collected is calculated using Equation 2-25.

$$V_{CH4} = 0.70 \times V_{bio} \qquad [2\text{-}25]$$

Appendix C presents an example calculation.

NO_x Emissions

NO_x is emitted when nitrogen compounds in biogas are oxidized and during the combustion process. No emission factors are available for biogas combustion that would incorporate both situations. Available NO_x emission factors for other fuels would underestimate emissions because lagoon biogas has higher nitrogen content than other fuels. Therefore, ERG estimates NO_x emissions using both emission factors and a calculation to estimate the amount of volatilized ammonia that will be oxidized to NO_x.

ERG used emission factors to estimate thermal NO_x formation. Thermal NO_x from flares was estimated using the AP-42 emission factors for landfill gas combustion flares. The landfill gas factors are based on combusting 100 percent methane. Because biogas comprises mainly methane (approximately 70 percent), the AP-42 landfill gas factors are expected to approximate emissions from biogas. The emissions from gas turbines were also estimated using emission factors in AP-42 for landfill gas.

ERG estimated NO_x calculated from oxidation of nitrogen compounds in the biogas, assuming a portion of the nitrogen compounds (i.e., ammonia) are converted to NO_x. Several technical articles provided a range of possible concentrations of ammonia in the biogas (Harper, et al., 2000; Ni, et al., 2000a). For this analysis, ERG used the maximum of the range, 1.67 percent ammonia by volume, to provide a conservative estimate. Equation 2-26 is used to calculate the volumetric flow rate of NH3 (V_{NH3}) in the biogas.

$$V_{NH3} = V_{bio} \times 0.0167 \tag{2-26}$$

When combusted, most of the ammonia will form N_2 rather than NO_x because the energy of formation for N_2 is lower. Consequently, assuming that all ammonia is converted to NO_x would be an overestimate. One technical article suggested that a maximum of 30 percent of ammonia would convert to NO_x (Harper, et al., 2000), which was used in the calculations. Equation 2-27 is used to calculate thermal NO_x.

$$M_{tNOx} = V_{CH4} \times C_{vol} \times \frac{EF}{1\times10^6} \times \frac{1}{C_{mass}} \qquad [2\text{-}27]$$

where:

M_{tNOx} = mass of thermal NO_x emitted (kg/yr)
C_{vol} = volume conversion factor = 35.314 ft^3/m^3
EF = emission factor = 40 lbs NO_x/ million ft^3 CH_4 combusted
C_{mass} = mass conversion factor = 2.2 lb/kg.

Equation 2-28 is used to estimate annual fuel NO_x emissions.

$$m_{fNOx} = \frac{P \times V_{NH3} \times MW_{NH3}}{R \times T \times 1000} \times \frac{MW_{NOx}}{MW_{NH3}} \times 0.3 \qquad [2\text{-}28]$$

where:

m_{fNOx} = annual fuel NO_x emissions (kg/yr)
MW_{NH3} = molecular weight of NH_3 = 17 g/mol
MW_{NOx} = molecular weight of NO_x (as N_2O) = 44 g/mol.

The total annual NO_x emission (m_{NOx}) is simply the sum of thermal and fuel NO_x emissions.

SO_2 Emissions

ERG estimates SO_2 emissions by assuming that the sulfur compounds in biogas are completely oxidized in both the flare and gas turbine. Several technical articles provided a range of possible concentrations of H_2S in the biogas (Ni, et al., 2000b). For this analysis, ERG used the maximum of the range, 0.36 percent H_2S by volume, to provide a conservative estimate. The H_2S volume (V_{H2S}) is calculated using Equation 2-29.

$$V_{H2S} = V_{bio} \times 0.0036 \qquad [2\text{-}29]$$

Equation 2-30 is used to estimate SO_2, assuming all the H_2S in the biogas is completely oxidized to SO_2.

$$m_{SO2} = \frac{P \times V_{H2S} \times MW_{H2S}}{R \times T \times 1000} \times \frac{MW_{SO2}}{MW_{H2S}} \qquad [2\text{-}30]$$

where:

m_{SO2}	=	mass of SO_2 emitted (kg/yr)
MW_{H2S}	=	molecular weight of H_2S = 34 g/mol
MW_{SO2}	=	molecular weight of SO_2 = 64 g/mol.

Appendix C contains a sample calculation of SO_2 emissions.

CO Emissions

CO emissions are generated from incomplete combustion of methane and other organic compounds in biogas. ERG estimated emissions using the AP-42 emission factors for landfill gas combustion (of methane). Landfill gas factors were used for the same reasons discussed for SO_2 (i.e., methane makes up the majority of biogas). Equation 2-31 is used to calculate CO emissions.

$$m_{CO} = V_{CH4} \times C_{vol} \times \frac{EF}{1 \times 10^6} \times \frac{1}{C_{mass}} \qquad [2\text{-}31]$$

where:

m_{CO}	=	mass of CO emitted (kg/yr)
C_{vol}	=	volume conversion factor = 35.314 ft^3/m^3
EF	=	emission factor = 750 lbs CO / million ft^3 CH_4 combusted (flaring)
C_{mass}	=	mass conversion factor = 2.2 lb/kg.

Appendix C presents a sample calculation of CO emissions.

2.3.3 Model Farm Emissions

Table 2.3-2 presents the total amount of biogas generated at dairies and swine, wet layer, and veal operations under Options 5 and 6. Tables 2.3-3 through 2.3-5 present the estimated criteria air pollutant emissions for swine, wet layer, and veal operations under Option 5, and for Large swine operations and dairies under Option 6.

Table 2.3-2
Total Biogas Generated - Options 5 and 6 (m^3/yr)

Animal Type	Size Class	System Type	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Option 5							
Veal	Medium 3	Flush	7,885	7,660	7,660	7,434	8,561
	Medium 2	Flush	3,943	3,830	3,830	3,717	4,280
	Medium 1	Flush	2,920	2,837	2,837	2,754	3,171
Swine	Large 2	Farrow-to-Finish	484,087	970,094	794,653	N/A	N/A
	Large 1	Farrow-to-Finish	211,533	198,858	198,045	N/A	N/A
	Medium 3	Farrow-to-Finish	N/A	122,693	123,749	N/A	N/A
	Medium 2	Farrow-to-Finish	N/A	86,027	83,956	N/A	N/A
	Medium 1	Farrow-to-Finish	N/A	47,944	46,809	N/A	N/A
Swine	Large 2	Grow-Finish	1,714,489	511,386	576,711	N/A	N/A
	Large 1	Grow-Finish	201,557	204,371	196,492	N/A	N/A
	Medium 3	Grow-Finish	N/A	125,590	122,139	N/A	N/A
	Medium 2	Grow-Finish	N/A	87,464	81,771	N/A	N/A
	Medium 1	Grow-Finish	N/A	55,377	51,754	N/A	N/A
Wet Layer	Large 1	Flush	N/A	N/A	N/A	N/A	246,174
	Medium 3	Flush	N/A	N/A	N/A	N/A	10,351
Option 6							
Dairy	Large 1	Flush	327,667	321,554	319,299	312,463	360,378
		Hose	50,421	52,230	49,975	51,060	59,368
Swine	Large 2	Farrow-to-Finish	484,087	970,094	794,653	N/A	N/A
		Grow-Finish	1,714,489	511,386	576,711	N/A	N/A
	Large 1	Farrow-to-Finish	211,533	198,858	198,045	N/A	N/A
		Grow-Finish	201,557	204,371	196,492	N/A	N/A

N/A- Not applicable.

Table 2.3-3

Model Farm Sulfur Dioxide[a] Emissions from Flaring (Option 5) and Digesters (Option 6) (kg/yr)

		Option 5 (Flare)					Option 6 (Gas Turbine)				
		Region					Region				
Animal Type	Size Class	Central	Mid-Atlantic	Midwest	Pacific	South	Central	Mid-Atlantic	Midwest	Pacific	South
Veal	Medium 1	28	27	27	26	30	N/A	N/A	N/A	N/A	N/A
	Medium 2	38	37	37	36	41	N/A	N/A	N/A	N/A	N/A
	Medium 3	76	73	73	71	82	N/A	N/A	N/A	N/A	N/A
Swine - Farrow-to-finish	Large 2	4,639	9,297	7,616	N/A	N/A	4,639	9,297	7,616	N/A	N/A
	Large 1	2,027	1,906	1,898	N/A	N/A	2,027	1,906	1,898	N/A	N/A
	Medium 1	N/A	459	449	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 2	N/A	824	805	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	1,176	1,186	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Swine - Grow Finish	Large 2	1,6431	4,901	5,527	N/A	N/A	1,6431	4,901	5,527	N/A	N/A
	Large 1	1,932	1959	1,883	N/A	N/A	1,932	1,959	1,883	N/A	N/A
	Medium 1	N/A	531	1,171	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 2	N/A	838	784	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	1204	496	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dairy[b] - Flush	Large 1	N/A	N/A	N/A	N/A	N/A	3,140	3,082	3,060	2,994	3,454
Dairy[b] - Hose	Large 1	N/A	N/A	N/A	N/A	N/A	483	501	479	489	569
Wet Layer	Large 1	N/A	N/A	N/A	N/A	2,359	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	N/A	N/A	N/A	99	N/A	N/A	N/A	N/A	N/A

[a]Assumes biogas contains 0.36% (by volume) hydrogen sulfide and complete oxidation to SO_2 during combustion.
[b]Number of head is the sum of mature cows, heifers, and calves.
N/A - Not applicable.

Table 2.3-4

Model Farm Carbon Monoxide Emissions from Flaring (Option 5) and Digesters (Option 6) (kg/yr)

		Option 5 (Flare)					Option 6 (Gas Turbine)				
		Region					Region				
Animal Type	**Size Class**	**Central**	**Mid-Atlantic**	**Midwest**	**Pacific**	**South**	**Central**	**Mid-Atlantic**	**Midwest**	**Pacific**	**South**
Veal	Medium 1	25	24	24	23	27	N/A	N/A	N/A	N/A	N/A
	Medium 2	33	32	32	31	36	N/A	N/A	N/A	N/A	N/A
	Medium 3	66	65	65	63	72	N/A	N/A	N/A	N/A	N/A
Swine - Farrow-to-finish	Large 2	4,079	8,175	6,697	N/A	N/A	1,251	2,507	2,054	N/A	N/A
	Large 1	1,783	1,676	1,669	N/A	N/A	547	514	512	N/A	N/A
	Medium 1	N/A	404	394	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 2	N/A	725	708	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	1,034	1,043	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Swine - Grow Finish	Large 2	14,448	4,310	4,860	N/A	N/A	4,431	1,322	1,490	N/A	N/A
	Large 1	1,699	1,722	1,656	N/A	N/A	521	528	508	N/A	N/A
	Medium 1	N/A	467	436	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 2	N/A	737	689	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	1,058	1,029	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dairy[a] - Flush	Large 1	N/A	N/A	N/A	N/A	N/A	847	831	825	808	931
Dairy[a] - Hose	Large 1	N/A	N/A	N/A	N/A	N/A	130	135	129	132	153
Wet Layer	Large 1	N/A	N/A	N/A	N/A	2,075	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	N/A	N/A	N/A	87	N/A	N/A	N/A	N/A	N/A

[a]Number of head is the sum of mature cows, heifers, and calves.
N/A - Not applicable.

Table 2.3-5

Model Farm Nitrogen Oxide[a] Emissions from Flaring (Option 5) and Digesters (Option 6) (kg/yr)

Animal	Size	Option 5 (Flare)					Option 6 (Gas Turbine)				
		Region					Region				
		Central	Mid-Atlantic	Midwest	Pacific	South	Central	Mid-Atlantic	Midwest	Pacific	South
Veal	Medium 1	28	27	27	26	30	N/A	N/A	N/A	N/A	N/A
	Medium 2	38	37	37	36	41	N/A	N/A	N/A	N/A	N/A
	Medium 3	76	74	74	72	82	N/A	N/A	N/A	N/A	N/A
Swine - Farrow-to-finish	Large 2	4,656	9,331	7,643	N/A	N/A	4,912	9,843	8,063	N/A	N/A
	Large 1	2,035	1,913	1,905	N/A	N/A	2,146	2,018	2,010	N/A	N/A
	Medium 1	N/A	461	450	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 2	N/A	827	808	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	1,180	1,190	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Swine - Grow-Finish	Large 2	16,491	4,919	5,547	N/A	N/A	17,396	5,189	5,852	N/A	N/A
	Large 1	1,939	1,966	1,890	N/A	N/A	2,045	2,074	1,994	N/A	N/A
	Medium 1	N/A	533	498	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 2	N/A	841	787	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	1,208	1,175	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dairy[b] - Flush	Large 1	N/A	N/A	N/A	N/A	N/A	3,325	3,263	3,240	3,170	3,657
Dairy[b] - Hose	Large 1	N/A	N/A	N/A	N/A	N/A	512	530	507	518	602
Wet Layer	Large 1	N/A	N/A	N/A	N/A	2,368	N/A	N/A	N/A	N/A	N/A
	Medium 3	N/A	N/A	N/A	N/A	100	N/A	N/A	N/A	N/A	N/A

[a]Assumes biogas contains 1.67% (by volume) NH_3 and 30% is converted to NOx during combustion. Includes thermal and fuel emissions.
[b]Number of head is the sum of mature cows, heifers, and calves.
N/A - Not applicable.

3.0 AIR EMISSIONS FROM LAND APPLICATION ACTIVITIES

Animal feeding operations generate air emissions from applying animal waste to cropland. Air emissions are primarily generated when ammonia volatilizes at the point the material is applied to land (Sutton et al., 2001). Additional amounts of nitrous oxide are emitted from agricultural soils when nitrogen applied to the soil undergoes nitrification and denitrification. Loss through denitrification depends upon the oxygen levels of the soil to which manure is applied. Low oxygen levels, resulting from wet, compacted, or warm soil, increase the amount of nitrate-nitrogen released to the air as nitrogen gas or nitrous oxide (OSUE, 2000a). However, a study by Sharpe and Harper (1997), which compared losses of ammonia and nitrous oxide from the sprinkler irrigation of swine effluent, concluded that ammonia emissions made a larger contribution to airborne nitrogen losses. The analysis of air emissions from land application activities focuses on the volatilization of nitrogen as both ammonia and nitrous oxide.

The amount of nitrogen released to the environment from applying animal waste depends upon the rate and method in which it is applied, the quantity of material applied, and site-specific factors such as air temperature, wind speed, and soil pH. There are insufficient data to quantify the effect of site-specific factors; therefore, they are not addressed in this report.

This section presents information on the effect of application rate and method on air emissions, as well as the methodology and results for air emission calculations based on the quantity of animal waste and commercial nitrogen applied.

3.1 Data Inputs

The calculation of ammonia and nitrous oxide emissions from land application activities uses the following data inputs:

- Ammonia emission factors for land application; and
- Amount of nitrogen in solid and liquid manure land applied on site and off site.

3.1.1 Ammonia Emission Factors

Table 3.1-1 presents nitrogen volatilization rates for six different land application methods obtained from the Midwest Plan Service: Livestock Waste Facilities Handbook (MWPS, 1983). As shown in this table, ammonia volatilizes at significantly different rates depending on the method used to apply manure. When manure is applied via an irrigation sprinkler, there is a greater surface area available from which the ammonia can volatilize. Typical sprinkler systems include towed big gun, stationary big gun, traveling big gun, handmove system, and surface system and towline system (MWPS, 1987). Midwest Plan Service reports an ammonia loss of 15 to 40 percent when a sprinkler irrigation system is used to apply liquid manure and a 10 to 25 percent ammonia loss when liquid manure is applied using a broadcast spreader; however, incorporating manure into the soil immediately after application can significantly reduce the amount of ammonia that volatilizes (MWPS, 1987). The manure can be incorporated into the soil through plowing or any other method that mixes the manure and soil. Data available from North Carolina State University suggests that ammonia emissions can be reduced by 25 percent if manure is incorporated within 48 hours following application (NCCES, 1994b). If manure is directly injected, the total ammonia volatilization could be as low as 1 to 5 percent.

Table 3.1-1

Percentage of Nitrogen Volatilizing as Ammonia from Land Application

Application Method	Percent Loss[a]	Avg Percent Loss
Broadcast (solid)	15-30	22.5
Broadcast (liquid)	10-25	17.5
Broadcast (solid, immediate incorporation)	1-5	3
Broadcast (liquid, immediate incorporation)	1-5	3
Knifing (liquid)	0-2	1
Sprinkler irrigation (liquid)	15-40	27.5

[a]MWPS, 1983. Percentage of nitrogen applied that is lost within 4 days of application.

Although facilities may change application techniques to conserve nitrogen, thereby significantly reducing the amount of ammonia that volatilizes, such changes are not dictated by the regulatory options. For this analysis, it is assumed that the application methods used by animal feeding operations do not significantly change from baseline. Based on this assumption, the rate at which ammonia volatilizes is not expected to change. If facilities choose to alter their application procedures to limit ammonia volatilization, this analysis may overestimate ammonia emissions due to manure application to cropland.

The application rate can also impact the volatilization rate if the amount of manure applied significantly builds up on the field surface, causing a mulching effect. For example, where manure is piled high enough to seal lower levels from exposure to the air, ammonia does not volatilize at the normal rate and anaerobic decomposition occurs. For this analysis, it is assumed that animal feeding operations do not apply enough waste under baseline conditions to cause mulching.

Under a phosphorus-based application scenario, facilities must apply supplemental nitrogen fertilizer to meet crop nutrient needs. The cost model assumes facilities apply commercial ammonium nitrate or urea. Ammonia emissions from applied commercial nitrogen are expected to be insignificant compared to those from applied manure. In a study sited by the Ohio State Extension, the loss of ammonia from surface-applied urea due to volatilization can range from 0 to 35 percent depending on the time of application until first rainfall (OSUE, 2000b). For example, if 10 mm of rain falls within two days, no loss is expected; however, if no rain falls within 6 days of application, losses can be greater than 30 percent. There is no significant danger of losing ammonium nitrate fertilizer to volatilization because it quickly converts to nitrate-nitrogen, which does not volatilize. For the purpose of this analysis, it is assumed that there are no significant losses from commercial fertilizer.

3.1.2 Manure Nitrogen Applied to Land

Because it is assumed that application methods do not change from baseline, only the quantity of waste applied to cropland on site and off site changes. On-site ammonia volatilization decreases as the quantity of waste applied to cropland on site decreases. However, since both on-site and off-site ammonia volatilization are considered, total ammonia volatilization is expected to remain constant. The movement of waste off site changes the location of the ammonia releases but not the quantity released.

ERG applies the same assumptions that are used in the cost methodology report (U.S. EPA, 2002a) to estimate compliance costs for land application of animal waste. To estimate the change in air emissions from applying nitrogen on and off site under baseline conditions and for each regulatory option, the cost methodology defines three types of animal feeding operations: Category 1 facilities currently have sufficient land to apply all manure on site; Category 2 facilities currently do not have enough land to apply all manure on site; and Category 3 facilities currently apply no manure on site. Neither Category 1 nor Category 3 facilities show a change in ammonia emission rates from the land application of animal manure under the regulatory options. Category 2 facilities apply their waste agronomically under the regulatory options, reducing the amount of manure applied on site and subsequently reducing ammonia emissions.

For the baseline scenario, it is assumed that some Category 2 facilities over-apply their manure and others apply manure agronomically and transport excess manure off site. Air emissions from facilities that already agronomically apply manure do not change from baseline. For facilities that over-apply manure under baseline conditions, the amount of nitrogen applied is calculated using cost model estimates of the amount of excreted nitrogen that can be applied to the field and the amount of nitrogen transported off site. Under each of the regulatory options, the rate of manure application changes to meet either the nitrogen or phosphorus needs of the crop. As a result, facilities that currently over-apply manure need to reduce the rate of application, thereby reducing the total amount of manure applied on site, and decreasing the amount of ammonia that volatilizes on site. Doing this, however, also increases the amount of manure applied off site and the amount of ammonia that volatilizes off site. In both the baseline and post-regulatory scenarios, Category 1 facilities apply all of their waste on site and Category 3 facilities apply all of their waste off site.

Under Option 5, anaerobic lagoons at all swine, poultry and veal operations are covered and the biogas vented to a flare. It is assumed that only 2 percent of the nitrogen entering the lagoon is lost as ammonia in biogas (Martin, 2002), which is ultimately oxidized to NO_x via flaring. When the lagoon is uncovered (baseline and all other regulatory options), it is calculated that 43.6 percent of the nitrogen entering the lagoon volatilizes as ammonia. Therefore, under Option 5, the manure from covered lagoons that is subsequently land applied contains more nitrogen, resulting in higher ammonia and nitrous oxide emissions to air.

Under Option 5A , all manure scraped from beef and dairy drylots, and all separated solids from beef, dairy and veal settling basins are composted. During the composting process, ammonia-nitrogen is either volatilized as ammonia or converted to more stable forms of nitrogen. Under baseline and all other regulatory options, the waste is sent to a stockpile (instead of a compost pile), where 20 percent of the nitrogen is expected to volatilize as ammonia (Sutton, 2001). It is assumed that 30 percent of the nitrogen volatilizes from the compost pile (Eghball, 1997). Because more ammonia volatilizes from the compost pile than the stockpile, and because the remaining nitrogen in the waste has been converted to a more stable form, the ammonia losses from land application under Option 5A are expected to decrease. Only 2 percent of the nitrogen in land-applied solid waste volatilizes as ammonia under Option 5A. The amount of liquid waste that volatilizes as ammonia under Option 5A remains the same as at baseline and under all other regulatory options. The nitrous oxide emissions from land application also decrease under Option 5A.

The application rates for liquid manure are calculated separately. The cost model first calculates the minimum number of acres that are needed to dispose of liquid manure based on the hydraulic loading capacity of the cropland and the nutrient assimilative capacity of the crops. The liquid manure is applied onsite first, until either the maximum hydraulic loading is reached or the nutrient or phosphorous needs of the crop are met. If the maximum hydraulic loading capacity is reached, but there is still a need for nitrogen or phosphorous on site, solid manure is applied (if available) until the nutrient assimilative capacity of the crops is met. Any additional liquid or solid manure that cannot be land applied on site due to maximum hydraulic loading or maximum nutrient capacity is transported and applied to land off site.

The cost model calculates the total amount of liquid and solid manure applied, broken out by size group, region, Category 1, Category 2, and Category 3 operations, high, medium, and low requirement operations, and the total amount of nitrogen and phosphorous in the land-applied manure (U.S. EPA, 2002a). Table 3.1-2 presents the pounds of solid and liquid nitrogen applied on and off site for each animal type under the different regulatory options.

3.2 Ammonia Emissions Methodology

Ammonia emissions resulting from the on-site and off-site application of manure to land is dependent on the ammonia volatilization rate (based primarily on the method of application) and the amount of manure that is applied both on site and off site.

3.2.1 Ammonia Volatilization Rates

The percent of nitrogen lost as ammonia as a result of land application activities depends on the both the application method used and the rate of incorporation. Both the application method and the rate of incorporation vary by animal operation; therefore, the percent nitrogen losses are calculated separately for beef feedlots, dairies and poultry and swine operations using Equation 3-1.

Table 3.1-2

Industry-Level Pounds of Nitrogen Going to Land Application

Animal Type	Option	On Site		Off Site	
		Solid	Liquid	Solid	Liquid
Beef	Baseline	119,360,643	35,053,523	261,574,770	18,753,422
	Option 1	100,695,691	34,922,656	280,239,740	18,884,289
	Options 2-4, 7	80,939,227	35,246,900	299,996,188	18,560,047
	Option 5A	80,939,227	35,246,900	299,996,188	18,560,047
	Option 6	80,939,227	35,246,900	299,996,188	18,560,047
Heifer	Baseline	2,278,598	1,978,404	255,707	224,271
	Option 1	2,153,638	1,977,582	380,667	225,093
	Options 2-4, 7	1,978,560	1,978,076	555,745	224,600
	Option 5A	1,978,560	1,978,076	555,745	224,600
	Option 6	1,978,560	1,978,076	555,745	224,600
Dairy	Baseline	97,450,887	38,646,497	39,922,164	12,110,681
	Option 1	54,970,419	30,391,950	82,402,634	20,365,228
	Options 2-4, 7	43,076,906	28,987,938	94,296,148	21,769,240
	Option 5A	43,076,906	28,987,938	94,296,148	21,769,240
	Option 6	43,076,906	28,987,938	94,296,148	21,769,240
Veal	Baseline	N/A	167,223	N/A	N/A
	Option 1	N/A	167,223	N/A	N/A
	Options 2-4, 7	N/A	167,223	N/A	N/A
	Option 5	N/A	346,204	N/A	N/A
	Option 6	N/A	167,223	N/A	N/A
Swine	Baseline	N/A	92,880,272	N/A	51,782,476
	Option 1	N/A	92,880,272	N/A	51,782,476
	Options 2-4, 7	N/A	171,863,826	N/A	76,230,805
	Option 5	N/A	166,384,460	N/A	194,592,872
	Option 6	N/A	72,714,440	N/A	39,819,251
Chicken	Baseline	128,830,953	7,535,132	275,739,455	15,933,802
	Option 1	128,830,953	7,535,132	275,739,455	15,933,802
	Options 2-4, 7	70,265,988	25,191,086	172,559,277	44,464,142
	Option 5	87,921,942	51,425,854	201,089,618	20,905,520
	Option 6	70,265,988	25,191,086	172,559,277	44,464,142

Table 3.1-2 (Continued)

Animal Type	Option	On Site		Off Site	
		Solid	Liquid	Solid	Liquid
Turkey	Baseline	47,770,936	N/A	149,239,024	N/A
	Option 1	47,770,936	N/A	149,239,024	N/A
	Options 2-4, 7	17,220,939	N/A	32,023,445	N/A
	Option 5	17,220,939	N/A	32,023,445	N/A
	Option 6	17,220,939	N/A	32,023,445	N/A

$$\% \text{ N Lost from Application} =$$

$$(\% \text{ Incorporated} \times \text{Average } \% \text{ Loss}) + (\% \text{ Land Applied} \times \text{Average } \% \text{ Loss}) \qquad [3\text{-}1]$$

where:

% Incorporated	=	The percentage of land-applied manure that is incorporated into the soil immediately after application.
Average % Loss	=	The average percentage of the ammonia lost from the land-application method used, obtained from Table 3.2-1. (This value is calculated by averaging the minimum and maximum percent loss for each application method.)
% Land Applied	=	The percentage of land-applied manure that is surface applied.

Table 3.2-1 presents the animal-specific volatilization rates.

Table 3.2-1

Percentage of Nitrogen Volatilizing as Ammonia from Land Application by Animal Type

	Percent Loss	
Animal Type	**Solid**	**Liquid**
Beef & Dairy	17%	20%
Poultry	20%	15%
Swine (Large)	-	20%
Swine (Medium)	-	23%

$$\% \text{ N Lost from Application} =$$

$$(\% \text{ Incorporated x Average } \% \text{ Loss}) + (\% \text{ Land Applied x Average } \% \text{ Loss}) \quad [3\text{-}1]$$

where:

% Incorporated	=	The percent of land applied manure that is incorporated into the soil immediately after application.
Average % Loss	=	The average percent of the ammonia lost from the land application method used, obtained from Table 3.2-1. (This value is calculated by averaging the minimum and maximum percent loss for each application method.)
% Land Applied	=	The percent of land applied manure that is surface applied.

Beef Feedlots and Dairies

For beef feedlots and dairies, it is assumed that 30 percent of the waste being land applied is incorporated and 70 percent of the waste is surface applied, assuming a sprinkler for liquid waste. Therefore, the expected nitrogen losses are calculated as follows, using the emission factors from Table 3.1-1:

$$\% \text{ N lost from liquid waste application} = (30\% \times 3\%) + (70\% \times 27.5\%) = 20\%$$

$$\% \text{ N lost from solid waste application} = (30\% \times 3\%) + (70\% \times 22.5\%) = 17\%$$

Poultry Operations

For poultry operations, it is assumed that 15 percent of the waste being land applied is incorporated and 85 percent of the waste is surface applied, assuming broadcast spreading of liquid waste. Therefore, the expected nitrogen losses are calculated as follows, using the emission factors from Table 3.1-1:

$$\% \text{ N lost from liquid waste application} = (15\% \times 3\%) + (85\% \times 17.5\%) = 15\%$$

$$\% \text{ N lost from solid waste application} = (15\% \times 3\%) + (85\% \times 22.5\%) = 20\%$$

Swine Operations

For Large swine operations, it is assumed that 30 percent of the waste being land applied is incorporated and 70 of the waste is surface applied using a sprinkler system. For Medium swine operations, it is assumed that 20 percent of the waste being land applied is incorporated and 80 of the waste is surface applied using a sprinkler system. All swine waste being land applied is liquid waste. Therefore, the expected nitrogen losses are calculated as follows, using the emission factors from Table 3.1-1:

$$\text{\% N lost from liquid waste application (Large)} = (30\% \times 3\%) + (70\% \times 27.5\%) = 20\%$$

$$\text{\% N lost from liquid waste application (Medium)} = (20\% \times 3\%) + (80\% \times 22.5\%) = 23\%$$

3.2.2 Calculation of Ammonia Emissions

Equations 3-2 through 3-5 are used to quantify ammonia emissions resulting from the on-site and off-site land application of liquid and solid animal waste:

$$\text{Ammonia Volatilization from Solid Waste, On Site (lb/yr)} = \text{\% N Lost from Solid Waste Application} \times (\text{Solid Nitrogen Applied On Site}) \quad [3\text{-}2]$$

$$\text{Ammonia Volatilization from Solid Waste, Off Site (lb/yr)} = \text{\% N Lost from Solid Waste Application} \times (\text{Solid Nitrogen Applied Off Site}) \quad [3\text{-}3]$$

$$\text{Ammonia Volatilization from Liquid Waste, On Site (lb/yr)} = \text{\% N Lost from Liquid Waste Application} \times (\text{Liquid Nitrogen Applied On Site}) \quad [3\text{-}4]$$

$$\text{Ammonia Volatilization from Liquid Waste, Off Site (lb/yr)} = \text{\% N Lost from Liquid Waste Application} \times (\text{Liquid Nitrogen Applied Off Site}) \quad [3\text{-}5]$$

The total amount of ammonia volatilized on site and off site is calculated by summing the amount of volatilized ammonia resulting from both solid and liquid waste application. Appendix D presents an example calculation of the amount of ammonia volatilized on and off site.

3.2.3 Model Farm Ammonia Emissions

Tables 3.2-2 and 3.2-3 present the total amount of ammonia volatilized on site and off site for each model farm by regulatory option and region. As discussed above, it is assumed that reducing in on-site nitrogen application also reduces on-site ammonia volatilization, and increasing off-site nitrogen application also increases off-site ammonia volatilization. These assumptions hold true if the application method before and after regulatory implementation remain the same.

Table 3.2-2

Industry-Level On-Site Ammonia Emissions from Land Application of Animal Waste by Regulatory Option (tons/yr)

Animal Type	Size Class	Regulatory Option	On-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Baseline	2,911	76	4,576	827	N/A
		Option 1	2,431	49	4,129	355	N/A
		Options 2-4,7	2,152	52	3,724	316	N/A
		Option 5A	730	39	2,057	250	N/A
		Option 6	2,152	52	3,724	316	N/A
	Large 1	Baseline	1,671	31	3,053	287	N/A
		Option 1	1,619	29	3,003	232	N/A
		Options 2-4,7	1,262	25	2,497	180	N/A
		Option 5A	306	12	794	93	N/A
		Option 6	1,262	25	2,497	180	N/A
Beef Medium CAFOs							
	Medium 3	Baseline	13.1	0.9	38.2	2.4	0.2
		Option 1	12.6	0.8	36.8	2.3	0.2
		Options 2-4, 7	12.2	0.8	35.8	2.3	0.2
		Option 5A	2.5	0.3	9.6	0.9	0.1
		Option 6	12.2	0.8	35.8	2.3	0.2
	Medium 2	Baseline	13.9	1.8	55.7	1.7	0.2
		Option 1	13.2	1.7	52.7	1.7	0.2
		Options 2-4,7	12.7	1.7	50.9	1.6	0.2
		Option 5A	2.6	0.7	13.8	0.6	0.1
		Option 6	12.7	1.7	50.9	1.6	0.2
	Medium 1	Baseline	17.1	2.2	68.3	2.2	0.3
		Option 1	15.8	2.1	63.0	2.1	0.3
		Options 2-4,7	14.9	1.9	59.6	1.9	0.2
		Option 5A	3.1	0.8	16.6	0.8	0.1
		Option 6	14.9	1.9	59.6	1.9	0.2

Table 3.2-2 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Large CAFOs							
	Large 1	Baseline	2,177	624	486	5,244	343
		Option 1	1,535	344	375	2,555	189
		Options 2-4,7	1,336	263	315	1,973	125
		Option 5A	796	140	155	1,272	68
		Option 6	1,336	263	315	1,973	125
Dairy Medium CAFOs							
	Medium 3	Baseline	85	123	89	95	42
		Option 1	67	100	70	74	31
		Options 2-4, 7	61	91	64	69	28
		Option 5A	26	33	20	34	16
		Option 6	61	91	64	69	28
	Medium 2	Baseline	115	404	414	66	70
		Option 1	81	292	293	45	44
		Options 2-4,7	72	247	256	38	37
		Option 5A	33	93	84	20	20
		Option 6	72	247	256	38	37
	Medium 1	Baseline	187	688	676	107	115
		Option 1	170	632	616	97	103
		Options 2-4,7	167	620	605	95	101
		Option 5A	62	200	168	42	50
		Option 6	167	620	605	95	101
Heifers Large CAFOs							
	Large 1	Baseline	172	N/A	N/A	129	N/A
		Option 1	167	N/A	N/A	126	N/A
		Options 2-4,7	160	N/A	N/A	121	N/A
		Option 5A	60	N/A	N/A	111	N/A
		Option 6	160	N/A	N/A	121	N/A

Table 3.2-2 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Heifers Medium CAFOs							
	Medium 3	Baseline	6.3	N/A	5.5	2.2	N/A
		Option 1	6.2	N/A	5.5	2.2	N/A
		Options 2-4, 7	6.0	N/A	5.4	2.3	N/A
		Option 5A	2.2	N/A	3.0	1.9	N/A
		Option 6	6.0	N/A	5.4	2.3	N/A
	Medium 2	Baseline	11.2	N/A	9.8	3.8	N/A
		Option 1	10.9	N/A	9.5	3.7	N/A
		Options 2-4,7	10.5	N/A	9.2	3.8	N/A
		Option 5A	3.9	N/A	5.2	3.2	N/A
		Option 6	10.5	N/A	9.2	3.8	N/A
	Medium 1	Baseline	2.8	N/A	47.4	1.6	N/A
		Option 1	2.7	N/A	45.4	1.5	N/A
		Options 2-4,7	2.5	N/A	44.1	1.5	N/A
		Option 5A	1.0	N/A	25.2	1.3	N/A
		Option 6	2.5	N/A	44.1	1.5	N/A
Veal Medium CAFOs							
	Medium 3	Baseline	0.9	N/A	14.6	N/A	N/A
		Option 1	0.9	N/A	14.6	N/A	N/A
		Options 2-4, 7	0.9	N/A	14.6	N/A	N/A
		Option 5A	1.9	N/A	30.2	N/A	N/A
		Option 6	0.9	N/A	14.6	N/A	N/A
	Medium 2	Baseline	0.1	N/A	0.4	N/A	N/A
		Option 1	0.1	N/A	0.4	N/A	N/A
		Options 2-4,7	0.1	N/A	0.4	N/A	N/A
		Option 5A	0.1	N/A	0.9	N/A	N/A
		Option 6	0.1	N/A	0.4	N/A	N/A
	Medium 1	Baseline	0.0	0	0.7	N/A	N/A
		Option 1	0.0	0	0.7	N/A	N/A
		Options 2-4,7	0.0	0	0.7	N/A	N/A
		Option 5A	0.1	0	1.4	N/A	N/A
		Option 6	0.0	0	0.7	N/A	N/A

Table 3.2-2 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Ammonia Emissions (tons/yr) Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow-Finish Large CAFOs							
	Large 2	Baseline	388	955	478	N/A	N/A
		Option 1	388	955	478	N/A	N/A
		Options 2-4,7	314	684	342	N/A	N/A
		Option 5	1,278	2,894	1,006	N/A	N/A
		Option 6	314	684	387	N/A	N/A
	Large 1	Baseline	79	429	444	N/A	N/A
		Option 1	79	429	444	N/A	N/A
		Options 2-4,7	70	355	367	N/A	N/A
		Option 5	272	1,236	897	N/A	N/A
		Option 6	70	355	367	N/A	N/A
Swine - Grow Finish Medium CAFOs							
	Medium 3	Baseline	N/A	20	44	N/A	N/A
		Option 1	N/A	20	44	N/A	N/A
		Options 2-4, 7	N/A	18	39	N/A	N/A
		Option 5	N/A	58	89	N/A	N/A
		Option 6	N/A	18	39	N/A	N/A
	Medium 2	Baseline	N/A	11	52	N/A	N/A
		Option 1	N/A	11	52	N/A	N/A
		Options 2-4,7	N/A	10	48	N/A	N/A
		Option 5	N/A	31	103	N/A	N/A
		Option 6	N/A	10	48	N/A	N/A
	Medium 1	Baseline	N/A	14	64	N/A	N/A
		Option 1	N/A	14	64	N/A	N/A
		Options 2-4,7	N/A	13	59	N/A	N/A
		Option 5	N/A	38	127	N/A	N/A
		Option 6	N/A	13	59	N/A	N/A

Table 3.2-2 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Farrow-to-Finish Large CAFOs							
	Large 2	Baseline	195	1,283	1,913	N/A	N/A
		Option 1	195	1,283	1,913	N/A	N/A
		Options 2-4,7	164	973	1,451	N/A	N/A
		Option 5	676	3,998	4,224	N/A	N/A
		Option 6	164	973	1,627	N/A	N/A
	Large 1	Baseline	131	254	991	N/A	N/A
		Option 1	131	254	991	N/A	N/A
		Options 2-4,7	120	222	865	N/A	N/A
		Option 5	450	755	2,106	N/A	N/A
		Option 6	120	222	865	N/A	N/A
Swine - Farrow-to-Finish Medium CAFOs							
	Medium 3	Baseline	N/A	16	88	N/A	N/A
		Option 1	N/A	16	88	N/A	N/A
		Options 2-4, 7	N/A	14	80	N/A	N/A
		Option 5	N/A	47	185	N/A	N/A
		Option 6	N/A	14	80	N/A	N/A
	Medium 2	Baseline	N/A	19	139	N/A	N/A
		Option 1	N/A	19	139	N/A	N/A
		Options 2-4,7	N/A	18	130	N/A	N/A
		Option 5	N/A	56	291	N/A	N/A
		Option 6	N/A	18	130	N/A	N/A
	Medium 1	Baseline	N/A	21	151	N/A	N/A
		Option 1	N/A	21	151	N/A	N/A
		Options 2-4,7	N/A	19	142	N/A	N/A
		Option 5	N/A	60	317	N/A	N/A
		Option 6	N/A	19	142	N/A	N/A

Table 3.2-2 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Ammonia Emissions (tons/yr) Central	Mid-Atlantic	Midwest	Pacific	South
Broilers Large CAFOs							
	Large 2	Baseline	N/A	1,399	N/A	N/A	3,404
		Option 1	N/A	1,399	N/A	N/A	3,404
		Options 2-4,7	N/A	1,014	N/A	N/A	2,780
		Option 5	N/A	1,014	N/A	N/A	2,780
		Option 6	N/A	1,014	N/A	N/A	2,780
	Large 1	Baseline	N/A	846	N/A	N/A	1,709
		Option 1	N/A	846	N/A	N/A	1,709
		Options 2-4,7	N/A	615	N/A	N/A	1,398
		Option 5	N/A	615	N/A	N/A	1,398
		Option 6	N/A	615	N/A	N/A	1,398
Broilers Medium CAFOs							
	Medium 3	Baseline	N/A	95	N/A	N/A	190
		Option 1	N/A	95	N/A	N/A	190
		Options 2-4, 7	N/A	71	N/A	N/A	158
		Option 5	N/A	71	N/A	N/A	158
		Option 6	N/A	71	N/A	N/A	158
	Medium 2	Baseline	N/A	69	N/A	N/A	125
		Option 1	N/A	69	N/A	N/A	125
		Options 2-4,7	N/A	52	N/A	N/A	103
		Option 5	N/A	52	N/A	N/A	103
		Option 6	N/A	52	N/A	N/A	103
	Medium 1	Baseline	N/A	40	N/A	N/A	63
		Option 1	N/A	40	N/A	N/A	63
		Options 2-4,7	N/A	30	N/A	N/A	53
		Option 5	N/A	30	N/A	N/A	53
		Option 6	N/A	30	N/A	N/A	53

Table 3.2-2 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Dry Large CAFOs							
	Large 2	Baseline	N/A	N/A	1,180	N/A	336
		Option 1	N/A	N/A	1,180	N/A	336
		Options 2-4,7	N/A	N/A	842	N/A	272
		Option 5	N/A	N/A	842	N/A	272
		Option 6	N/A	N/A	842	N/A	272
	Large 1	Baseline	N/A	N/A	2,365	N/A	1,040
		Option 1	N/A	N/A	2,365	N/A	1,040
		Options 2-4,7	N/A	N/A	1,639	N/A	827
		Option 5	N/A	N/A	1,639	N/A	827
		Option 6	N/A	N/A	1,639	N/A	827
Layer - Dry Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	1.4	N/A	0.8
		Option 1	N/A	N/A	1.4	N/A	0.8
		Options 2-4, 7	N/A	N/A	1.0	N/A	0.7
		Option 5	N/A	N/A	1.0	N/A	0.7
		Option 6	N/A	N/A	1.0	N/A	0.7
	Medium 2	Baseline	N/A	N/A	4.9	N/A	3.2
		Option 1	N/A	N/A	4.9	N/A	3.2
		Options 2-4,7	N/A	N/A	3.4	N/A	2.6
		Option 5	N/A	N/A	3.4	N/A	2.6
		Option 6	N/A	N/A	3.4	N/A	2.6
	Medium 1	Baseline	N/A	N/A	6.9	N/A	6.0
		Option 1	N/A	N/A	6.9	N/A	6.0
		Options 2-4,7	N/A	N/A	5.3	N/A	5.1
		Option 5	N/A	N/A	5.3	N/A	5.1
		Option 6	N/A	N/A	5.3	N/A	5.1
Layer - Wet Large CAFOs							
	Large 1	Baseline	N/A	N/A	N/A	N/A	564
		Option 1	N/A	N/A	N/A	N/A	564
		Options 2-4,7	N/A	N/A	N/A	N/A	479
		Option 5	N/A	N/A	N/A	N/A	3,573
		Option 6	N/A	N/A	N/A	N/A	479

Table 3.2-2 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Ammonia Emissions (tons/yr) Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Wet Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	N/A	N/A	1.5
		Option 1	N/A	N/A	N/A	N/A	1.5
		Options 2-4, 7	N/A	N/A	N/A	N/A	1.3
		Option 5	N/A	N/A	N/A	N/A	10.0
		Option 6	N/A	N/A	N/A	N/A	1.3
Turkey Large CAFOs							
	Large 1	Baseline	N/A	1,011	1,454	N/A	N/A
		Option 1	N/A	1,011	1,454	N/A	N/A
		Options 2-4,7	N/A	692	995	N/A	N/A
		Option 5	N/A	692	995	N/A	N/A
		Option 6	N/A	1,011	1,454	N/A	N/A
Turkey Medium CAFOs							
	Medium 3	Baseline	N/A	9.0	5.1	N/A	N/A
		Option 1	N/A	9.0	5.1	N/A	N/A
		Options 2-4, 7	N/A	5.7	3.3	N/A	N/A
		Option 5	N/A	5.7	3.3	N/A	N/A
		Option 6	N/A	5.7	3.3	N/A	N/A
	Medium 2	Baseline	N/A	12.5	6.8	N/A	N/A
		Option 1	N/A	12.5	6.8	N/A	N/A
		Options 2-4,7	N/A	8.1	4.4	N/A	N/A
		Option 5	N/A	8.1	4.4	N/A	N/A
		Option 6	N/A	8.1	4.4	N/A	N/A
	Medium 1	Baseline	N/A	13.7	7.3	N/A	N/A
		Option 1	N/A	13.7	7.3	N/A	N/A
		Options 2-4,7	N/A	8.9	4.7	N/A	N/A
		Option 5	N/A	8.9	4.7	N/A	N/A
		Option 6	N/A	8.9	4.7	N/A	N/A

N/A - Not Applicable.

Table 3.2-3

Industry-Level Off-Site Ammonia Emissions from Land Application of Animal Waste by Regulatory Option (tons/yr)

Animal Type	Size Class	Regulatory Option	Off-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Baseline	7,130	141	14,396	529	N/A
		Option 1	7,610	168	14,843	1,001	N/A
		Options 2-4,7	7,888	166	15,248	1,041	N/A
		Option 5A	1,233	43	2,829	259	N/A
		Option 6	7,888	166	15,248	1,041	N/A
	Large 1	Baseline	602	10	1,250	36	N/A
		Option 1	654	12	1,300	91	N/A
		Options 2-4,7	1,011	17	1,806	143	N/A
		Option 5A	138	4	314	29	N/A
		Option 6	1,011	17	1,806	143	N/A
Beef Medium CAFOs							
	Medium 3	Baseline	1.0	0.1	2.9	0.2	0.0
		Option 1	1.4	0.1	4.3	0.3	0.0
		Options 2-4, 7	1.8	0.1	5.2	0.3	0.0
		Option 5A	0.3	0.0	1.0	0.1	0.0
		Option 6	1.8	0.1	5.2	0.3	0.0
	Medium 2	Baseline	1.0	0.2	4.2	0.1	0.0
		Option 1	1.7	0.2	7.1	0.2	0.0
		Options 2-4,7	2.2	0.3	9.0	0.3	0.0
		Option 5A	0.3	0.1	1.6	0.1	0.0
		Option 6	2.2	0.3	9.0	0.3	0.0
	Medium 1	Baseline	1.3	0.2	5.1	0.2	0.0
		Option 1	2.5	0.3	10.5	0.3	0.0
		Options 2-4,7	3.5	0.5	13.9	0.5	0.1
		Option 5A	0.5	0.1	2.4	0.1	0.0
		Option 6	3.5	0.5	13.9	0.5	0.1

Table 3.2-3 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Large CAFOs							
	Large 1	Baseline	1,580	283	415	1,479	265
		Option 1	2,222	564	526	4,168	419
		Options 2-4,7	2,421	645	586	4,750	483
		Option 5A	638	179	122	1,674	223
		Option 6	2,421	645	586	4,750	483
Dairy Medium CAFOs							
	Medium 3	Baseline	14	26	14	16	7
		Option 1	31	50	33	37	18
		Options 2-4, 7	37	59	39	42	20
		Option 5A	8	11	7	10	6
		Option 6	37	59	39	42	20
	Medium 2	Baseline	19	94	67	11	11
		Option 1	53	207	188	32	37
		Options 2-4,7	62	252	226	38	44
		Option 5A	13	52	38	11	17
		Option 6	62	252	226	38	44
	Medium 1	Baseline	30	126	110	18	19
		Option 1	47	181	170	28	31
		Options 2-4,7	50	194	181	30	33
		Option 5A	13	43	37	9	10
		Option 6	50	194	181	30	33
Heifers Large CAFOs							
	Large 1	Baseline	21	N/A	N/A	16	N/A
		Option 1	26	N/A	N/A	19	N/A
		Options 2-4,7	33	N/A	N/A	24	N/A
		Option 5A	9	N/A	N/A	15	N/A
		Option 6	33	N/A	N/A	24	N/A

Table 3.2-3 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Heifers Medium CAFOs							
	Medium 3	Baseline	0.5	N/A	0.5	0.2	N/A
		Option 1	0.6	N/A	0.5	0.2	N/A
		Options 2-4, 7	0.8	N/A	0.7	0.1	N/A
		Option 5A	0.2	N/A	0.3	0.1	N/A
		Option 6	0.8	N/A	0.7	0.1	N/A
	Medium 2	Baseline	0.8	N/A	0.7	0.3	N/A
		Option 1	1.1	N/A	1.0	0.4	N/A
		Options 2-4,7	1.6	N/A	1.3	0.3	N/A
		Option 5A	0.4	N/A	0.5	0.3	N/A
		Option 6	1.6	N/A	1.3	0.3	N/A
	Medium 1	Baseline	0.2	N/A	3.6	0.1	N/A
		Option 1	0.3	N/A	5.6	0.2	N/A
		Options 2-4,7	0.5	N/A	6.8	0.2	N/A
		Option 5A	0.1	N/A	2.3	0.1	N/A
		Option 6	0.5	N/A	6.8	0.2	N/A
Swine - Grow-Finish Large CAFOs							
	Large 2	Baseline	165	406	203	N/A	N/A
		Option 1	165	406	203	N/A	N/A
		Options 2-4,7	238	677	339	N/A	N/A
		Option 5	601	913	324	N/A	N/A
		Option 6	238	677	293	N/A	N/A
	Large 1	Baseline	21	116	121	N/A	N/A
		Option 1	21	116	121	N/A	N/A
		Options 2-4,7	31	191	197	N/A	N/A
		Option 5	70	290	210	N/A	N/A
		Option 6	31	191	197	N/A	N/A
Swine - Grow-Finish Medium CAFOs							
	Medium 3	Baseline	N/A	4.7	10.3	N/A	N/A
		Option 1	N/A	4.7	10.3	N/A	N/A
		Options 2-4, 7	N/A	7.0	15.3	N/A	N/A
		Option 5	N/A	12.1	18.3	N/A	N/A
		Option 6	N/A	7.0	15.3	N/A	N/A

Table 3.2-3 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow-Finish Medium CAFOs (cont.)							
	Medium 2	Baseline	N/A	2.3	10.7	N/A	N/A
		Option 1	N/A	2.3	10.7	N/A	N/A
		Options 2-4,7	N/A	3.1	14.7	N/A	N/A
		Option 5	N/A	5.9	19.6	N/A	N/A
		Option 6	N/A	3.1	14.7	N/A	N/A
	Medium 1	Baseline	N/A	2.8	13.2	N/A	N/A
		Option 1	N/A	2.8	13.2	N/A	N/A
		Options 2-4,7	N/A	3.9	18.2	N/A	N/A
		Option 5	N/A	7.4	24.3	N/A	N/A
		Option 6	N/A	3.9	18.2	N/A	N/A
Swine - Farrow-to-Finish Large CAFOs							
	Large 2	Baseline	102	672	1,002	N/A	N/A
		Option 1	102	672	1,002	N/A	N/A
		Options 2-4,7	134	981	1,463	N/A	N/A
		Option 5	336	1,702	1,837	N/A	N/A
		Option 6	134	981	1,288	N/A	N/A
	Large 1	Baseline	25	49	192	N/A	N/A
		Option 1	25	49	192	N/A	N/A
		Options 2-4,7	36	82	318	N/A	N/A
		Option 5	81	129	354	N/A	N/A
		Option 6	36	82	318	N/A	N/A
Swine - Farrow-to-Finish Medium CAFOs							
	Medium 3	Baseline	N/A	2.4	13.6	N/A	N/A
		Option 1	N/A	2.4	13.6	N/A	N/A
		Options 2-4, 7	N/A	3.8	21.2	N/A	N/A
		Option 5	N/A	6.4	25.7	N/A	N/A
		Option 6	N/A	3.8	21.2	N/A	N/A
	Medium 2	Baseline	N/A	2.2	16.4	N/A	N/A
		Option 1	N/A	2.2	16.4	N/A	N/A
		Options 2-4,7	N/A	3.4	24.8	N/A	N/A
		Option 5	N/A	6.0	31.5	N/A	N/A
		Option 6	N/A	3.4	24.8	N/A	N/A

Table 3.2-3 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Farrow-to-Finish Medium CAFOs (cont.)							
	Medium 1	Baseline	N/A	2.4	17.9	N/A	N/A
		Option 1	N/A	2.4	17.9	N/A	N/A
		Options 2-4,7	N/A	3.7	27.0	N/A	N/A
		Option 5	N/A	6.5	34.3	N/A	N/A
		Option 6	N/A	3.7	27.0	N/A	N/A
Broilers Large CAFOs							
	Large 2	Baseline	N/A	2,394	N/A	N/A	5,826
		Option 1	N/A	2,394	N/A	N/A	5,826
		Options 2-4,7	N/A	2,779	N/A	N/A	6,450
		Option 5	N/A	2,779	N/A	N/A	6,450
		Option 6	N/A	2,779	N/A	N/A	6,450
	Large 1	Baseline	N/A	846	N/A	N/A	3,069
		Option 1	N/A	846	N/A	N/A	3,069
		Options 2-4,7	N/A	1,749	N/A	N/A	3,380
		Option 5	N/A	1,749	N/A	N/A	3,380
		Option 6	N/A	1,749	N/A	N/A	3,380
Broilers Medium CAFOs							
	Medium 3	Baseline	N/A	194	N/A	N/A	388
		Option 1	N/A	194	N/A	N/A	388
		Options 2-4, 7	N/A	218	N/A	N/A	421
		Option 5	N/A	218	N/A	N/A	421
		Option 6	N/A	218	N/A	N/A	421
	Medium 2	Baseline	N/A	141	N/A	N/A	254
		Option 1	N/A	141	N/A	N/A	254
		Options 2-4,7	N/A	159	N/A	N/A	275
		Option 5	N/A	159	N/A	N/A	275
		Option 6	N/A	159	N/A	N/A	275
	Medium 1	Baseline	N/A	82	N/A	N/A	130
		Option 1	N/A	82	N/A	N/A	130
		Options 2-4,7	N/A	92	N/A	N/A	140
		Option 5	N/A	92	N/A	N/A	140
		Option 6	N/A	92	N/A	N/A	140

Table 3.2-3 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Dry Large CAFOs							
	Large 2	Baseline	N/A	N/A	4,508	N/A	1,283
		Option 1	N/A	N/A	4,508	N/A	1,283
		Options 2-4,7	N/A	N/A	4,846	N/A	1,347
		Option 5	N/A	N/A	4,846	N/A	1,347
		Option 6	N/A	N/A	4,846	N/A	1,347
	Large 1	Baseline	N/A	N/A	5,377	N/A	2,363
		Option 1	N/A	N/A	5,377	N/A	2,363
		Options 2-4,7	N/A	N/A	6,103	N/A	2,576
		Option 5	N/A	N/A	6,103	N/A	2,576
		Option 6	N/A	N/A	6,103	N/A	2,576
Layer - Dry Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	3.2	N/A	1.9
		Option 1	N/A	N/A	3.2	N/A	1.9
		Options 2-4, 7	N/A	N/A	3.6	N/A	2.1
		Option 5	N/A	N/A	3.6	N/A	2.1
		Option 6	N/A	N/A	3.6	N/A	2.1
	Medium 2	Baseline	N/A	N/A	11.2	N/A	7.3
		Option 1	N/A	N/A	11.2	N/A	7.3
		Options 2-4,7	N/A	N/A	12.8	N/A	8.0
		Option 5	N/A	N/A	12.8	N/A	8.0
		Option 6	N/A	N/A	12.8	N/A	8.0
	Medium 1	Baseline	N/A	N/A	12.6	N/A	10.9
		Option 1	N/A	N/A	12.6	N/A	10.9
		Options 2-4,7	N/A	N/A	14.2	N/A	11.8
		Option 5	N/A	N/A	14.2	N/A	11.8
		Option 6	N/A	N/A	14.2	N/A	11.8
Layer - Wet Large CAFOs							
	Large 1	Baseline	N/A	N/A	N/A	N/A	1,192
		Option 1	N/A	N/A	N/A	N/A	1,192
		Options 2-4,7	N/A	N/A	N/A	N/A	1,276
		Option 5	N/A	N/A	N/A	N/A	2,396
		Option 6	N/A	N/A	N/A	N/A	1,276

Table 3.2-3 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Ammonia Emissions (tons/yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Wet Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	N/A	N/A	3.1
		Option 1	N/A	N/A	N/A	N/A	3.1
		Options 2-4, 7	N/A	N/A	N/A	N/A	3.3
		Option 5	N/A	N/A	N/A	N/A	6.0
		Option 6	N/A	N/A	N/A	N/A	3.3
Turkey Large CAFOs							
	Large 1	Baseline	N/A	1,794	2,581	N/A	N/A
		Option 1	N/A	1,794	2,581	N/A	N/A
		Options 2-4,7	N/A	2,113	3,040	N/A	N/A
		Option 5	N/A	2,113	3,040	N/A	N/A
		Option 6	N/A	2,113	3,040	N/A	N/A
Turkey Medium CAFOs							
	Medium 3	Baseline	N/A	13.3	7.6	N/A	N/A
		Option 1	N/A	13.3	7.6	N/A	N/A
		Options 2-4, 7	N/A	16.5	9.4	N/A	N/A
		Option 5	N/A	16.5	9.4	N/A	N/A
		Option 6	N/A	16.5	9.4	N/A	N/A
	Medium 2	Baseline	N/A	15.8	8.6	N/A	N/A
		Option 1	N/A	15.8	8.6	N/A	N/A
		Options 2-4,7	N/A	20.2	11.0	N/A	N/A
		Option 5	N/A	20.2	11.0	N/A	N/A
		Option 6	N/A	20.2	11.0	N/A	N/A
	Medium 1	Baseline	N/A	17.3	9.2	N/A	N/A
		Option 1	N/A	17.3	9.2	N/A	N/A
		Options 2-4,7	N/A	22.1	11.8	N/A	N/A
		Option 5	N/A	22.1	11.8	N/A	N/A
		Option 6	N/A	22.1	11.8	N/A	N/A

N/A - Not Applicable.

3.3 Nitrous Oxide Emissions Methodology

Nitrous oxide emissions resulting from the on-site and off-site application of manure to land also depends upon the amount of manure nitrogen applied, which was determined as described in Section 3.1.2.

3.3.1 Calculation of Nitrous Oxide Emissions

ERG calculates nitrous oxide emissions based on the methodology described in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000* (U.S. EPA, 2002b). This methodology estimates that 1.25 percent of the nitrogen that is land applied but does not volatilize to ammonia will be emitted as nitrous oxide. It is also assumed that one percent of the nitrogen that volatilizes as ammonia will eventually become nitrous oxide.

Based on the methodology above, Equation 3-6 is used to quantify nitrous oxide losses from on-site application of solid waste:

$$\begin{gathered}\text{Nitrous Oxide Emissions from Solid Waste, On Site (lb/yr)} = \\ (1 - \text{\% N Lost from Solid Waste Application}) \times (\text{Solid Nitrogen Applied On Site}) \times 1.25\% \times \frac{44\ N_2O}{28\ N} + \\ (\text{\% N Lost from Solid Waste Application}) \times (\text{Solid Nitrogen Applied On Site}) \times 1\% \times \frac{44\ N_2O}{28\ N}\end{gathered} \qquad [3\text{-}6]$$

Equation 3-6 can be modified to calculate losses from solid and liquid waste, both on site and off site, as shown for the ammonia volatilization calculations above.

The total amount of nitrous oxide emitted on site and off site is calculated by summing the emissions resulting from both solid and liquid waste application. Appendix D presents an example calculation of the amount of nitrous oxide emitted on site and off site.

3.3.2 Model Farm Nitrous Oxide Emissions

Tables 3.3-1 and 3.3-2 present the total amount of nitrous oxide emitted on site and off site for each model farm by regulatory option and region. It is assumed that reducing on-site nitrogen application also reduces on-site nitrous oxide emissions, and increasing off-site nitrogen application also increases off-site nitrous oxide emissions. These assumptions hold true if the application method before and after regulatory implementation remains the same.

Table 3.3-1

Industry-Level On-Site Nitrous Oxide Emissions from Land Application of Animal Waste by Regulatory Option (Mg CO_2 Eq./yr)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Baseline	91,044	2,249	137,360	25,363	N/A
		Option 1	73,659	1,348	120,669	9,971	N/A
		Options 2-4,7	64,919	1,433	107,949	8,729	N/A
		Option 5A	66,490	1,447	109,791	8,802	N/A
		Option 6	64,919	1,433	107,949	8,729	N/A
	Large 1	Baseline	53,040	956	95,619	8,811	N/A
		Option 1	49,935	856	91,637	6,907	N/A
		Options 2-4,7	38,752	722	75,624	5,266	N/A
		Option 5A	39,808	737	77,506	5,363	N/A
		Option 6	38,752	722	75,624	5,266	N/A
Beef Medium CAFOs							
	Medium 3	Baseline	405	26	1,170	72	7
		Option 1	391	25	1,125	70	7
		Options 2-4, 7	379	24	1,096	67	7
		Option 5A	389	25	1,125	69	7
		Option 6	379	24	1,096	67	7
	Medium 2	Baseline	431	54	1,704	52	7
		Option 1	409	52	1,613	50	7
		Options 2-4,7	394	50	1,554	47	6
		Option 5A	405	51	1,595	48	6
		Option 6	394	50	1,554	47	6
	Medium 1	Baseline	528	66	2,091	67	8
		Option 1	489	61	1,923	62	7
		Options 2-4,7	459	57	1,817	57	7
		Option 5A	473	59	1,864	59	7
		Option 6	459	57	1,817	57	7

Table 3.3-1 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr) Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Large CAFOs							
	Large 1	Baseline	65,821	19,165	14,931	158,583	10,245
		Option 1	44,670	10,133	11,123	73,901	5,480
		Options 2-4,7	38,420	7,640	9,238	56,180	3,624
		Option 5A	39,017	7,775	9,415	56,954	3,687
		Option 6	38,420	7,640	9,238	56,180	3,624
Dairy Medium CAFOs							
	Medium 3	Baseline	2,551	3,747	2,711	2,851	1,230
		Option 1	2,002	3,010	2,142	2,195	902
		Options 2-4, 7	1,808	2,723	1,941	2,018	823
		Option 5A	1,846	2,787	1,990	2,056	837
		Option 6	1,808	2,723	1,941	2,018	823
	Medium 2	Baseline	3,456	12,271	12,681	1,965	2,066
		Option 1	2,406	8,802	8,925	1,327	1,289
		Options 2-4,7	2,114	7,382	7,721	1,116	1,086
		Option 5A	2,157	7,552	7,910	1,136	1,105
		Option 6	2,114	7,382	7,721	1,116	1,086
	Medium 1	Baseline	5,626	20,880	20,683	3,204	3,396
		Option 1	5,103	19,148	18,809	2,885	3,004
		Options 2-4,7	5,002	18,749	18,455	2,817	2,943
		Option 5A	5,118	19,213	18,938	2,877	2,999
		Option 6	5,002	18,749	18,455	2,817	2,943
Heifers Large CAFOs							
	Large 1	Baseline	5,163	N/A	N/A	3,524	N/A
		Option 1	5,018	N/A	N/A	3,428	N/A
		Options 2-4,7	4,791	N/A	N/A	3,261	N/A
		Option 5A	4,901	N/A	N/A	3,273	N/A
		Option 6	4,791	N/A	N/A	3,261	N/A

Table 3.3-1 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions ($Mg\ CO_2$ Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Heifers Medium CAFOs							
	Medium 3	Baseline	189	N/A	161	60	N/A
		Option 1	187	N/A	159	59	N/A
		Options 2-4, 7	181	N/A	155	62	N/A
		Option 5A	185	N/A	158	62	N/A
		Option 6	181	N/A	155	62	N/A
	Medium 2	Baseline	338	N/A	284	103	N/A
		Option 1	329	N/A	276	100	N/A
		Options 2-4,7	315	N/A	265	104	N/A
		Option 5A	322	N/A	270	104	N/A
		Option 6	315	N/A	265	104	N/A
	Medium 1	Baseline	83	N/A	1,378	43	N/A
		Option 1	80	N/A	1,314	41	N/A
		Options 2-4,7	74	N/A	1,275	41	N/A
		Option 5A	76	N/A	1,296	41	N/A
		Option 6	74	N/A	1,275	41	N/A
Veal Medium CAFOs							
	Medium 3	Baseline	24.2	N/A	387.4	N/A	N/A
		Option 1	24.2	N/A	387.4	N/A	N/A
		Options 2-4, 7	24.2	N/A	387.4	N/A	N/A
		Option 5A	50.1	N/A	802.0	N/A	N/A
		Option 6	24.2	N/A	387.4	N/A	N/A
	Medium 2	Baseline	1.2	N/A	11.6	N/A	N/A
		Option 1	1.2	N/A	11.6	N/A	N/A
		Options 2-4,7	1.2	N/A	11.6	N/A	N/A
		Option 5A	2.5	N/A	24.1	N/A	N/A
		Option 6	1.2	N/A	11.6	N/A	N/A
	Medium 1	Baseline	0.9	0.4	17.8	N/A	N/A
		Option 1	0.9	0.4	17.8	N/A	N/A
		Options 2-4,7	0.9	0.4	17.8	N/A	N/A
		Option 5A	1.9	0.7	36.8	N/A	N/A
		Option 6	0.9	0.4	17.8	N/A	N/A

Table 3.3-1 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow-Finish Large CAFOs							
	Large 2	Baseline	7,165	17,652	8,830	N/A	N/A
		Option 1	7,165	17,652	8,830	N/A	N/A
		Options 2-4,7	5,809	12,640	6,323	N/A	N/A
		Option 5	23,610	53,476	18,600	N/A	N/A
		Option 6	5,809	12,640	7,158	N/A	N/A
	Large 1	Baseline	1,459	7,925	8,204	N/A	N/A
		Option 1	1,459	7,925	8,204	N/A	N/A
		Options 2-4,7	1,291	6,556	6,787	N/A	N/A
		Option 5	5,021	22,834	16,574	N/A	N/A
		Option 6	1,291	6,556	6,787	N/A	N/A
Swine - Grow-Finish Medium CAFOs							
	Medium 3	Baseline	N/A	328	715	N/A	N/A
		Option 1	N/A	328	715	N/A	N/A
		Options 2-4, 7	N/A	291	634	N/A	N/A
		Option 5	N/A	934	1,432	N/A	N/A
		Option 6	N/A	291	634	N/A	N/A
	Medium 2	Baseline	N/A	177	837	N/A	N/A
		Option 1	N/A	177	837	N/A	N/A
		Options 2-4,7	N/A	163	771	N/A	N/A
		Option 5	N/A	502	1,662	N/A	N/A
		Option 6	N/A	163	771	N/A	N/A
	Medium 1	Baseline	N/A	219	1,036	N/A	N/A
		Option 1	N/A	219	1,036	N/A	N/A
		Options 2-4,7	N/A	202	954	N/A	N/A
		Option 5	N/A	621	2,055	N/A	N/A
		Option 6	N/A	202	954	N/A	N/A

Table 3.3-1 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Farrow-to-Finish Large CAFOs							
	Large 2	Baseline	3,611	23,702	35,346	N/A	N/A
		Option 1	3,611	23,702	35,346	N/A	N/A
		Options 2-4,7	3,030	17,983	26,817	N/A	N/A
		Option 5	12,492	73,891	78,069	N/A	N/A
		Option 6	3,030	17,983	30,064	N/A	N/A
	Large 1	Baseline	2,417	4,695	18,318	N/A	N/A
		Option 1	2,417	4,695	18,318	N/A	N/A
		Options 2-4,7	2,212	4,098	15,986	N/A	N/A
		Option 5	8,320	13,960	38,920	N/A	N/A
		Option 6	2,212	4,098	15,986	N/A	N/A
Swine - Farrow-to-Finish Medium CAFOs							
	Medium 3	Baseline	N/A	253	1,422	N/A	N/A
		Option 1	N/A	253	1,422	N/A	N/A
		Options 2-4, 7	N/A	231	1,299	N/A	N/A
		Option 5	N/A	752	3,000	N/A	N/A
		Option 6	N/A	231	1,299	N/A	N/A
	Medium 2	Baseline	N/A	305	2,243	N/A	N/A
		Option 1	N/A	305	2,243	N/A	N/A
		Options 2-4,7	N/A	287	2,106	N/A	N/A
		Option 5	N/A	898	4,706	N/A	N/A
		Option 6	N/A	287	2,106	N/A	N/A
	Medium 1	Baseline	N/A	332	2,446	N/A	N/A
		Option 1	N/A	332	2,446	N/A	N/A
		Options 2-4,7	N/A	312	2,297	N/A	N/A
		Option 5	N/A	978	5,132	N/A	N/A
		Option 6	N/A	312	2,297	N/A	N/A

Table 3.3-1 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Broilers Large CAFOs							
	Large 2	Baseline	N/A	25,853	N/A	N/A	62,913
		Option 1	N/A	25,853	N/A	N/A	62,913
		Options 2-4,7	N/A	18,747	N/A	N/A	51,384
		Option 5	N/A	18,747	N/A	N/A	51,384
		Option 6	N/A	18,747	N/A	N/A	51,384
	Large 1	Baseline	N/A	15,627	N/A	N/A	31,584
		Option 1	N/A	15,627	N/A	N/A	31,584
		Options 2-4,7	N/A	11,360	N/A	N/A	25,835
		Option 5	N/A	11,360	N/A	N/A	25,835
		Option 6	N/A	11,360	N/A	N/A	25,835
Broilers Medium CAFOs							
	Medium 3	Baseline	N/A	1,755	N/A	N/A	3,519
		Option 1	N/A	1,755	N/A	N/A	3,519
		Options 2-4, 7	N/A	1,306	N/A	N/A	2,918
		Option 5	N/A	1,306	N/A	N/A	2,918
		Option 6	N/A	1,306	N/A	N/A	2,918
	Medium 2	Baseline	N/A	1,279	N/A	N/A	2,303
		Option 1	N/A	1,279	N/A	N/A	2,303
		Options 2-4,7	N/A	952	N/A	N/A	1,910
		Option 5	N/A	952	N/A	N/A	1,910
		Option 6	N/A	952	N/A	N/A	1,910
	Medium 1	Baseline	N/A	735	N/A	N/A	1,167
		Option 1	N/A	735	N/A	N/A	1,167
		Options 2-4,7	N/A	549	N/A	N/A	971
		Option 5	N/A	549	N/A	N/A	971
		Option 6	N/A	549	N/A	N/A	971

Table 3.3-1 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Dry Large CAFOs							
	Large 2	Baseline	N/A	N/A	21,802	N/A	6,203
		Option 1	N/A	N/A	21,802	N/A	6,203
		Options 2-4,7	N/A	N/A	15,560	N/A	5,019
		Option 5	N/A	N/A	15,560	N/A	5,019
		Option 6	N/A	N/A	15,560	N/A	5,019
	Large 1	Baseline	N/A	N/A	43,708	N/A	19,211
		Option 1	N/A	N/A	43,708	N/A	19,211
		Options 2-4,7	N/A	N/A	30,292	N/A	15,280
		Option 5	N/A	N/A	30,292	N/A	15,280
		Option 6	N/A	N/A	30,292	N/A	15,280
Layer - Dry Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	26	N/A	15
		Option 1	N/A	N/A	26	N/A	15
		Options 2-4, 7	N/A	N/A	18	N/A	12
		Option 5	N/A	N/A	18	N/A	12
		Option 6	N/A	N/A	18	N/A	12
	Medium 2	Baseline	N/A	N/A	91	N/A	60
		Option 1	N/A	N/A	91	N/A	60
		Options 2-4,7	N/A	N/A	63	N/A	47
		Option 5	N/A	N/A	63	N/A	47
		Option 6	N/A	N/A	63	N/A	47
	Medium 1	Baseline	N/A	N/A	128	N/A	110
		Option 1	N/A	N/A	128	N/A	110
		Options 2-4,7	N/A	N/A	98	N/A	93
		Option 5	N/A	N/A	98	N/A	93
		Option 6	N/A	N/A	98	N/A	93

Table 3.3-1 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Wet Large CAFOs							
	Large 1	Baseline	N/A	N/A	N/A	N/A	13,719
		Option 1	N/A	N/A	N/A	N/A	13,719
		Options 2-4,7	N/A	N/A	N/A	N/A	11,662
		Option 5	N/A	N/A	N/A	N/A	86,961
		Option 6	N/A	N/A	N/A	N/A	11,662
Layer - Wet Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	N/A	N/A	37
		Option 1	N/A	N/A	N/A	N/A	37
		Options 2-4, 7	N/A	N/A	N/A	N/A	32
		Option 5	N/A	N/A	N/A	N/A	244
		Option 6	N/A	N/A	N/A	N/A	32
Turkey Large CAFOs							
	Large 1	Baseline	N/A	18,677	26,873	N/A	N/A
		Option 1	N/A	18,677	26,873	N/A	N/A
		Options 2-4,7	N/A	12,784	18,393	N/A	N/A
		Option 5	N/A	12,784	18,393	N/A	N/A
		Option 6	N/A	12,784	18,393	N/A	N/A
Turkey Medium CAFOs							
	Medium 3	Baseline	N/A	166	94	N/A	N/A
		Option 1	N/A	166	94	N/A	N/A
		Options 2-4, 7	N/A	106	60	N/A	N/A
		Option 5	N/A	106	60	N/A	N/A
		Option 6	N/A	106	60	N/A	N/A
	Medium 2	Baseline	N/A	231	125	N/A	N/A
		Option 1	N/A	231	125	N/A	N/A
		Options 2-4,7	N/A	150	81	N/A	N/A
		Option 5	N/A	150	81	N/A	N/A
		Option 6	N/A	150	81	N/A	N/A

Table 3.3-1 (Continued)

Animal Type	Size Class	Regulatory Option	On-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Turkey Medium CAFOs (cont.)							
	Medium 1	Baseline	N/A	252	135	N/A	N/A
		Option 1	N/A	252	135	N/A	N/A
		Options 2-4,7	N/A	164	88	N/A	N/A
		Option 5	N/A	164	88	N/A	N/A
		Option 6	N/A	164	88	N/A	N/A

NA - Not Applicable.

Table 3.3-2

Industry-Level Off-Site Nitrous Oxide Emissions from Land Application of Animal Waste by Regulatory Option (Mg CO_2 Eq./yr)

Animal Type	Size Class	Regulatory Option	Off-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Baseline	228,725	4,397	459,063	16,216	N/A
		Option 1	237,186	5,149	460,192	30,672	N/A
		Options 2-4,7	245,926	5,064	472,912	31,914	N/A
		Option 5A	253,279	5,199	486,632	32,777	N/A
		Option 6	245,926	5,064	472,912	31,914	N/A
	Large 1	Baseline	19,351	303	39,659	1,089	N/A
		Option 1	20,436	375	40,111	2,770	N/A
		Options 2-4,7	31,618	508	56,124	4,411	N/A
		Option 5A	32,582	522	57,772	4,537	N/A
		Option 6	31,618	508	56,124	4,411	N/A
Beef Medium CAFOs							
	Medium 3	Baseline	30.5	2.2	88.0	5.4	0.5
		Option 1	45.0	3.0	133.3	8.0	0.8
		Options 2-4, 7	57.0	3.8	162.1	10.4	1.0
		Option 5A	58.7	3.9	166.7	10.7	1.1
		Option 6	57.0	3.8	162.1	10.4	1.0
	Medium 2	Baseline	32.4	4.8	128.3	3.9	0.5
		Option 1	53.9	7.1	219.7	6.5	0.9
		Options 2-4,7	69.6	9.4	277.9	8.9	1.1
		Option 5A	71.6	9.6	286.0	9.1	1.2
		Option 6	69.6	9.4	277.9	8.9	1.1
	Medium 1	Baseline	39.7	6.2	157.4	5.0	0.6
		Option 1	78.9	10.4	324.8	9.9	1.3
		Options 2-4,7	108.2	14.5	431.3	14.5	1.8
		Option 5A	111.5	14.9	444.0	14.9	1.8
		Option 6	108.2	14.5	431.3	14.5	1.8

Table 3.3-2 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Large CAFOs							
	Large 1	Baseline	49,203	8,786	13,096	44,728	7,990
		Option 1	67,788	17,168	16,215	125,237	12,403
		Options 2-4,7	74,038	19,662	18,100	142,958	14,259
		Option 5A	76,007	20,176	18,613	146,357	14,547
		Option 6	74,038	19,662	18,100	142,958	14,259
Dairy Medium CAFOs							
	Medium 3	Baseline	415	798	441	464	200
		Option 1	965	1,535	1,010	1,120	528
		Options 2-4, 7	1,159	1,823	1,211	1,297	607
		Option 5A	1,192	1,876	1,247	1,333	622
		Option 6	1,159	1,823	1,211	1,297	607
	Medium 2	Baseline	563	2,883	2,064	320	336
		Option 1	1,613	6,351	5,820	958	1,113
		Options 2-4,7	1,905	7,771	7,025	1,170	1,317
		Option 5A	1,959	7,991	7,232	1,200	1,347
		Option 6	1,905	7,771	7,025	1,170	1,317
	Medium 1	Baseline	916	3,841	3,367	522	553
		Option 1	1,439	5,573	5,241	840	944
		Options 2-4,7	1,540	5,971	5,595	908	1,005
		Option 5A	1,581	6,138	5,754	932	1,031
		Option 6	1,540	5,971	5,595	908	1,005
Heifers Large CAFOs							
	Large 1	Baseline	653	N/A	N/A	438	N/A
		Option 1	783	N/A	N/A	532	N/A
		Options 2-4,7	1,010	N/A	N/A	698	N/A
		Option 5A	1,037	N/A	N/A	709	N/A
		Option 6	1,010	N/A	N/A	698	N/A

Table 3.3-2 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Heifers Medium CAFOs							
	Medium 3	Baseline	16.4	N/A	14.5	4.5	N/A
		Option 1	18.1	N/A	15.7	5.7	N/A
		Options 2-4, 7	24.3	N/A	20.1	2.7	N/A
		Option 5A	25.0	N/A	20.6	2.6	N/A
		Option 6	24.3	N/A	20.1	2.7	N/A
	Medium 2	Baseline	25.4	N/A	21.4	7.7	N/A
		Option 1	34.8	N/A	29.9	10.5	N/A
		Options 2-4,7	48.3	N/A	40.6	6.9	N/A
		Option 5A	49.7	N/A	41.6	6.9	N/A
		Option 6	48.3	N/A	40.6	6.9	N/A
	Medium 1	Baseline	6.3	N/A	103.7	3.2	N/A
		Option 1	9.9	N/A	167.8	5.0	N/A
		Options 2-4,7	15.2	N/A	206.7	4.7	N/A
		Option 5A	15.6	N/A	211.7	4.8	N/A
		Option 6	15.2	N/A	206.7	4.7	N/A
Swine - Grow-Finish Large CAFOs							
	Large 2	Baseline	3,044	7,498	3,751	N/A	N/A
		Option 1	3,044	7,498	3,751	N/A	N/A
		Options 2-4,7	4,400	12,510	6,258	N/A	N/A
		Option 5	11,101	16,865	5,997	N/A	N/A
		Option 6	4,400	12,510	5,423	N/A	N/A
	Large 1	Baseline	396	2,152	2,228	N/A	N/A
		Option 1	396	2,152	2,228	N/A	N/A
		Options 2-4,7	564	3,521	3,645	N/A	N/A
		Option 5	1,286	5,366	3,883	N/A	N/A
		Option 6	564	3,521	3,645	N/A	N/A

Table 3.3-2 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow-Finish Medium CAFOs							
	Medium 3	Baseline	N/A	76	166	N/A	N/A
		Option 1	N/A	76	166	N/A	N/A
		Options 2-4, 7	N/A	113	247	N/A	N/A
		Option 5	N/A	195	297	N/A	N/A
		Option 6	N/A	113	247	N/A	N/A
	Medium 2	Baseline	N/A	37	172	N/A	N/A
		Option 1	N/A	37	172	N/A	N/A
		Options 2-4,7	N/A	51	239	N/A	N/A
		Option 5	N/A	96	318	N/A	N/A
		Option 6	N/A	51	239	N/A	N/A
	Medium 1	Baseline	N/A	45	214	N/A	N/A
		Option 1	N/A	45	214	N/A	N/A
		Options 2-4,7	N/A	62	295	N/A	N/A
		Option 5	N/A	119	393	N/A	N/A
		Option 6	N/A	62	295	N/A	N/A
Swine - Farrow-to-Finish Large CAFOs							
	Large 2	Baseline	1,892	12,417	18,517	N/A	N/A
		Option 1	1,892	12,417	18,517	N/A	N/A
		Options 2-4,7	2,473	18,137	27,046	N/A	N/A
		Option 5	6,219	31,459	33,955	N/A	N/A
		Option 6	2,473	18,137	23,799	N/A	N/A
	Large 1	Baseline	468	909	3,548	N/A	N/A
		Option 1	468	909	3,548	N/A	N/A
		Options 2-4,7	673	1,507	5,880	N/A	N/A
		Option 5	1,491	2,380	6,541	N/A	N/A
		Option 6	673	1,507	5,880	N/A	N/A

Table 3.3-2 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Farrow-to-Finish Medium CAFOs							
	Medium 3	Baseline	N/A	39	220	N/A	N/A
		Option 1	N/A	39	220	N/A	N/A
		Options 2-4, 7	N/A	61	343	N/A	N/A
		Option 5	N/A	104	416	N/A	N/A
		Option 6	N/A	61	343	N/A	N/A
	Medium 2	Baseline	N/A	36	265	N/A	N/A
		Option 1	N/A	36	265	N/A	N/A
		Options 2-4,7	N/A	55	401	N/A	N/A
		Option 5	N/A	97	509	N/A	N/A
		Option 6	N/A	55	401	N/A	N/A
	Medium 1	Baseline	N/A	39	289	N/A	N/A
		Option 1	N/A	39	289	N/A	N/A
		Options 2-4,7	N/A	59	437	N/A	N/A
		Option 5	N/A	105	555	N/A	N/A
		Option 6	N/A	105	555	N/A	N/A
Broilers Large CAFOs							
	Large 2	Baseline	N/A	44,248	N/A	N/A	107,677
		Option 1	N/A	44,248	N/A	N/A	107,677
		Options 2-4,7	N/A	51,354	N/A	N/A	119,205
		Option 5	N/A	51,354	N/A	N/A	119,205
		Option 6	N/A	51,354	N/A	N/A	119,205
	Large 1	Baseline	N/A	28,059	N/A	N/A	56,710
		Option 1	N/A	28,059	N/A	N/A	56,710
		Options 2-4,7	N/A	32,325	N/A	N/A	62,459
		Option 5	N/A	32,325	N/A	N/A	62,459
		Option 6	N/A	32,325	N/A	N/A	62,459

Table 3.3-2 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Broilers Medium CAFOs							
	Medium 3	Baseline	N/A	3,578	N/A	N/A	7,174
		Option 1	N/A	3,578	N/A	N/A	7,174
		Options 2-4, 7	N/A	4,027	N/A	N/A	7,774
		Option 5	N/A	4,027	N/A	N/A	7,774
		Option 6	N/A	4,027	N/A	N/A	7,774
	Medium 2	Baseline	N/A	2,608	N/A	N/A	4,695
		Option 1	N/A	2,608	N/A	N/A	4,695
		Options 2-4,7	N/A	2,936	N/A	N/A	5,088
		Option 5	N/A	2,936	N/A	N/A	5,088
		Option 6	N/A	2,936	N/A	N/A	5,088
	Medium 1	Baseline	N/A	1,508	N/A	N/A	2,396
		Option 1	N/A	1,508	N/A	N/A	2,396
		Options 2-4,7	N/A	1,693	N/A	N/A	2,592
		Option 5	N/A	1,693	N/A	N/A	2,592
		Option 6	N/A	1,693	N/A	N/A	2,592
Layer - Dry Large CAFOs							
	Large 2	Baseline	N/A	N/A	83,308	N/A	23,703
		Option 1	N/A	N/A	83,308	N/A	23,703
		Options 2-4,7	N/A	N/A	89,550	N/A	24,887
		Option 5	N/A	N/A	89,550	N/A	24,887
		Option 6	N/A	N/A	89,550	N/A	24,887
	Large 1	Baseline	N/A	N/A	99,371	N/A	43,678
		Option 1	N/A	N/A	99,371	N/A	43,678
		Options 2-4,7	N/A	N/A	112,786	N/A	47,609
		Option 5	N/A	N/A	112,786	N/A	47,609
		Option 6	N/A	N/A	112,786	N/A	47,609

Table 3.3-2 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Layer - Dry Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	59	N/A	35
		Option 1	N/A	N/A	59	N/A	35
		Options 2-4, 7	N/A	N/A	67	N/A	38
		Option 5	N/A	N/A	67	N/A	38
		Option 6	N/A	N/A	67	N/A	38
	Medium 2	Baseline	N/A	N/A	208	N/A	136
		Option 1	N/A	N/A	208	N/A	136
		Options 2-4,7	N/A	N/A	236	N/A	148
		Option 5	N/A	N/A	236	N/A	148
		Option 6	N/A	N/A	236	N/A	148
	Medium 1	Baseline	N/A	N/A	233	N/A	202
		Option 1	N/A	N/A	233	N/A	202
		Options 2-4,7	N/A	N/A	263	N/A	219
		Option 5	N/A	N/A	263	N/A	219
		Option 6	N/A	N/A	263	N/A	219
Layer - Wet Large CAFOs							
	Large 1	Baseline	N/A	N/A	N/A	N/A	29,010
		Option 1	N/A	N/A	N/A	N/A	29,010
		Options 2-4,7	N/A	N/A	N/A	N/A	31,067
		Option 5	N/A	N/A	N/A	N/A	58,318
		Option 6	N/A	N/A	N/A	N/A	31,067
Layer - Wet Medium CAFOs							
	Medium 3	Baseline	N/A	N/A	N/A	N/A	76
		Option 1	N/A	N/A	N/A	N/A	76
		Options 2-4, 7	N/A	N/A	N/A	N/A	81
		Option 5	N/A	N/A	N/A	N/A	139
		Option 6	N/A	N/A	N/A	N/A	81

Table 3.3-2 (Continued)

Animal Type	Size Class	Regulatory Option	Off-Site Nitrous Oxide Emissions (Mg CO_2 Eq./yr)				
			Central	Mid-Atlantic	Midwest	Pacific	South
Turkey Large CAFOs							
	Large 1	Baseline	N/A	33,150	47,696	N/A	N/A
		Option 1	N/A	33,150	47,696	N/A	N/A
		Options 2-4,7	N/A	39,043	55,176	N/A	N/A
		Option 5	N/A	39,043	56,176	N/A	N/A
		Option 6	N/A	39,043	55,176	N/A	N/A
Turkey Medium CAFOs							
	Medium 3	Baseline	N/A	245	140	N/A	N/A
		Option 1	N/A	245	140	N/A	N/A
		Options 2-4, 7	N/A	305	174	N/A	N/A
		Option 5	N/A	305	174	N/A	N/A
		Option 6	N/A	305	174	N/A	N/A
	Medium 2	Baseline	N/A	293	158	N/A	N/A
		Option 1	N/A	293	158	N/A	N/A
		Options 2-4,7	N/A	374	202	N/A	N/A
		Option 5	N/A	374	202	N/A	N/A
		Option 6	N/A	374	202	N/A	N/A
	Medium 1	Baseline	N/A	319	171	N/A	N/A
		Option 1	N/A	319	171	N/A	N/A
		Options 2-4,7	N/A	408	218	N/A	N/A
		Option 5	N/A	408	218	N/A	N/A
		Option 6	N/A	408	218	N/A	N/A

N/A - Not Applicable.

4.0 AIR EMISSIONS FROM VEHICLES

Animal feeding operations that transport their manure off site and/or compost their manure on site use equipment (e.g., trucks, tractors) that release criteria air pollutants when operated. This section presents the methodology and results for calculating the increased criteria air pollutant emissions from off-site transportation and from composting manure on site. This document does not present information on potential changes in criteria air pollutant emissions that might arise from changes in commercial fertilizer manufacture and transport resulting from the rule.

4.1 Off-Site Transportation

Criteria air emissions from the off-site transportation of animal manure are evaluated for each of the seven regulatory options considered by EPA, as all options result in an increase of off-site transportation of manure at some operations. The cost model computes costs for three types of facilities:

- Category 1 operations have sufficient cropland to apply all manure on site;
- Category 2 operations do not have enough cropland to apply all waste on site and may or may not currently transport waste; and
- Category 3 operations have no cropland and currently transport all manure off site.

Because Category 1 operations emit no criteria air pollutants from vehicles at baseline, nor will any regulatory options induce them to do so, there are no current or projected emissions in criteria air emissions for this category. Category 2 operations, however, incur costs for transporting manure off site, increasing the amount of criteria air pollutants generated by these operations. Although Category 3 facilities currently transport their manure, a regulation that requires phosphorous-based application rather than a nitrogen-based application may cause facilities to transport their excess manure a further distance; therefore, the amount of criteria air pollutants generated by these operations may increase for options that require phosphorus-based application. EPA calculated air emission estimates for the off-site transportation of manure for all Category 2 facilities, as well as for Category 3 facilities that are expected to follow a phosphorus-based application regime.

4.1.1 Emissions Methodology

The beef and dairy cost model analyzed two different waste transportation options (U.S. EPA, 2002a). One considers the cost of purchasing trucks to transport waste, and the other evaluates the cost of paying a contractor to haul the waste off site. Because of the different methods used to estimate the costs of the two transportation options, two methods are used to calculate air emissions. Estimates of air emissions from operations purchasing waste transportation vehicles are based on the cost model calculations of the number of trucks purchased and the annual number of miles traveled. Contract-hauling emissions estimates are based on the cost model calculations of the annual amount of waste generated, the annual number of miles traveled, and truck sizes. The assumptions and equations used in each of the options are detailed below. Appendix E describes in detail the data and methodology used to calculate emissions from vehicles used for off-site transportation.

The swine and poultry cost model assumes that all operations hire a contractor to haul waste off site; therefore, emissions estimates are calculated using the contract-hauling methodology (U.S. EPA, 2002a).

The following assumptions are common to both transportation methods (Jewell et al., 1997):

- Vehicles for manure transport are diesel-fueled;
- Vehicles for manure transport have 300 brake-horsepower (bhp) engines;
- Vehicles for manure transport travel at an average speed of 35 miles/hr;
- Liquid manure is applied on site before solid manure;

- Liquid waste and semisolid waste are transported separately;
- The amount of waste hauled off site depends on the rate at which nutrients are applied (nitrogen (N)-based application versus phosphorus (P)-based application); and
- The reduction in volume typically obtained during composting is offset by wheat, straw, and water added to facilitate composting.

Emission Factors

The number of trucks, number of trips per truck, amount of solid and liquid waste, and transportation distance are all calculated in the cost model. Volatile organic compounds, nitrogen oxides, and carbon monoxide emissions (presented in grams per mile traveled) are calculated based on emission factors for diesel-fueled vehicles generated in MOBILE6 (U.S. EPA, 2002c). These MOBILE6 emission factors differentiate between emissions generated from solid waste haulers and liquid tanker trucks. Sulfur dioxide was not calculated here because MOBILE6 only estimates emission factors for hydrocarbons, carbon monoxide, and oxides of nitrogen (U.S. EPA, 2002a). The emission factor for particulate matter is listed in the AP-42 Manual (U.S. EPA, 1985) and does not differentiate between solid waste haulers and liquid tanker trucks (in grams per brake horsepower-hour). Assuming that vehicles for manure transport have 300 brake-horsepower (bhp) engines, and that they travel at an average speed of 35 miles per hour, the particulate matter emission factor can be expressed in units of grams per mile, as shown in Equation 4-1. Table 4.1-1 presents all of these emission factors.

$$\begin{gathered}\text{Purchase Matter Emission Factor (grams/miles) Miles (miles/yr)} = \\ \text{Purchase Matter Emission Factor (gm/bhp-hr)} \times \text{(1 hr/35 miles)} \times \text{300 bhp}\end{gathered} \qquad [4\text{-}1]$$

The amount of manure transported off site depends on the rate at which manure is applied (nitrogen-based application or phosphorous-based application), treatment of the manure (anaerobic digestion or no digestion), and whether or not the manure is composted.

Table 4.1-1

Emission Factors for Diesel Vehicles

Criteria Air Pollutant	Vehicle Emission Factor (grams/mile)	
	Solid Waste Hauler	Liquid Waste Tanker
VOCs[a]	1.08	1.35
NO_x[a]	23.67	27.6
CO[a]	5.87	7.83
PM[b]	0.857	0.857

[a]Source: U.S. EPA. 2002. MOBILE6.
[b]Source: U.S. EPA. 1985. AP-42 Manual.

4.1.2 Transportation Methods

Four potential methods of transporting manure off site can be used for beef, dairy, and heifer estimates: contract hauling, contract hauling with composting, purchasing a truck, and purchasing a truck with composting. The cost model is designed to select the most cost-effective method of transporting manure for each operation. The purchasing options consider the cost of purchasing trucks to haul the wastes off site and the round trip distance the trucks must travel; the contract options consider the cost of paying a contractor to haul the waste off site and the one-way distance the trucks must travel.

To estimate the miles traveled for each transportation option, the cost model performs calculations separately for the following variables: Category 2 versus Category 3, purchasing trucks versus hiring a contract hauler, solid waste versus liquid waste, nitrogen-based application versus phosphorous-based application.

<u>Purchasing Trucks</u>

Estimates of air emissions from operations purchasing waste transportation vehicles are based on the cost model calculations of the number of trucks purchased at each facility, the number of trips made, and the round trip miles traveled by each truck. The methodology used to calculate transport miles for purchasing a truck or purchasing a truck with composting is provided in Equation 4-2.

$$\begin{aligned}&\text{Purchase Truck Transport Miles (miles/yr)}\\&= \text{Number of Trucks} \times \text{Number of Trips per Truck (trips/yr)} \times \text{Round Trip Miles per Trip (miles/trip)}\end{aligned} \qquad [4\text{-}2]$$

The number of trucks, the number of trips per truck, and the miles per round trip each vary by category, waste consistency, and nutrient management basis. Therefore, there are essentially eight variations of this equation. When accounting for both purchasing a truck or purchasing a truck with composting, the number of variations of the equation doubles to sixteen.

Contract Hauling

For the contract-hauling option, ERG conducted telephone interviews with waste-hauling companies to estimate the size of the trucks used to transport both solid and liquid wastes (ERG, 1999). The truck size estimates are used to determine the number of trips that the contract hauler makes.

The hauling emission estimates are based on the cost model calculations of the weight (lbs) of waste being transported (converted to the number of trips per year by dividing by an average size truck based on conversations with haulers), multiplied by the one-way hauling distance. The methodology used to calculate miles traveled by contract haulers or contract haulers with composting (for both liquid and solid waste) is provided in Equation 4-3.

$$\begin{aligned}&\text{Contract Truck Transport Miles, Solid Waste (miles/yr)}\\&= \frac{\text{Solid Waste (lbs/yr)} \times \text{(Round trip haul distance/2) (miles)}}{\text{Solid waste truck size (tons)}}\end{aligned} \qquad [4\text{-}3]$$

The total annual miles traveled (by both purchase truck and contract-hauling options) is calculated for both Category 2 and Category 3 operations, broken out by solid and liquid waste. ERG calculates these mileages using the total number of facilities, the cost model frequency factors for N-based and P-based application, cost model frequency factors for Category 2 and Category 3 operations, the cost model frequency factor for N-based operations that already transport off site at baseline, and the total miles traveled to transport either solid or liquid waste. Table 4.1-2 presents the total miles traveled transporting solid and liquid waste for each animal sector.

The amount of criteria air pollutants released annually is calculated using these solid and liquid waste total annual miles, along with the emission factors listed in Table 4.1-1 and Equation 4-4. The emissions from each pollutant are calculated separately for both solid and liquid waste transportation.

$$\text{Total Pollutant, Emitted (tons)} = \frac{\text{Total Miles, Solid (miles)} \times \text{Pollutant Emision Factor, Solid (grams/miles)}}{\text{(454 grams/pound)} \times \text{(2000 pounds/ton)}} \quad [4\text{-}4]$$

Finally, the total pollutants emitted from the transportation of waste are calculated by summing those generated while hauling solid waste and those generated while hauling liquid waste. A sample calculation for total tons of pollutant emitted is shown in Equation 4-5.

$$\text{Total Pollutant, Emitted (tons)} = \text{Pollutant Emitted, Solid (tons)} + \text{Pollutant Emitted, Liquid (tons)} \quad [4\text{-}5]$$

Tables 4.1-3 through 4.1-6 summarize the results of the transportation criteria air pollution emission calculations for Category 2 and Category 3 operations by model farm, regulatory option, and region. Transportation emissions are reported as the incremental increase in criteria air pollutants from baseline for Category 2 and Category 3 operations. These tables show that additional criteria air pollutants are released in all cases. Increased emissions from Option 1 are less than the increase resulting from Options 2 through 7. The additional emissions from Options 2 through 7 are a result of the P-based application rate. At this rate, additional

Table 4.1-2

Industry Miles Traveled for Off Site Transportation

Animal Type	Option	Industry Miles	
		Solid	Liquid
Beef	Option 1	714,907	335,475
	Options 2-4, 7	6,396,268	7,003,664
	Option 5	6,393,267	7,003,664
	Option 6	6,396,268	7,003,664
Heifer	Option 1	26,486	1,223
	Options 2-4, 7	212,523	123,068
	Option 5	213,933	123,068
	Option 6	212,523	123,068
Dairy	Option 1	959,068	27,757,298
	Options 2-4, 7	2,975,472	60,203,111
	Option 5	2,945,912	58,723,328
	Option 6	2,975,472	60,203,111
Swine	Option 1	N/A	1,284,633
	Options 2-4, 7	N/A	21,953,750
	Option 5	N/A	11,325,047
	Option 6	N/A	21,147,101
Chicken	Option 1	1,404,896	192,111
	Options 2-4, 7	5,813,576	642,423
	Option 5	5,813,576	260,993
	Option 6	5,813,576	642,423
Turkey	Option 1	181,812	N/A
	Options 2-4, 7	1,385,485	N/A
	Option 5	1,385,485	N/A
	Option 6	1,385,485	N/A

Table 4.1-3

Industry-Level Incremental VOC Emissions above Baseline from Transportation of Manure Off Site by Regulatory Option (lbs/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Option 1	505.4	56.9	320.9	688.1	N/A
		Options 2-4,7	9,783.2	2,504.2	11,363.0	8,851.3	N/A
		Option 5A	9,783.2	2,502.5	11,363.0	8,846.2	N/A
		Option 6	9,783.2	2,504.2	11,363.0	8,851.3	N/A
	Large 1	Option 1	55.3	14.3	131.5	937.3	N/A
		Options 2-4,7	1,531.0	209.2	1,568.5	630.1	N/A
		Option 5A	1,530.8	208.8	1,568.5	630.1	N/A
		Option 6	1,531.0	209.2	1,568.5	630.1	N/A
Beef Medium CAFOs							
	Medium 3	Option 1	0.5	0.0	1.0	0.1	0.0
		Options 2-4,7	4.4	1.4	7.8	2.0	0.2
		Option 5A	4.4	1.4	7.8	2.0	0.2
		Option 6	4.4	1.4	7.8	2.0	0.2
	Medium 2	Option 1	0.7	0.1	2.1	0.1	0.0
		Options 2-4,7	4.4	2.9	11.9	1.5	0.1
		Option 5A	4.4	2.9	11.9	1.5	0.1
		Option 6	4.4	2.9	11.9	1.5	0.1
	Medium 1	Option 1	1.3	0.5	3.8	0.3	0.1
		Options 2-4,7	5.8	3.8	15.6	2.0	0.2
		Option 5A	5.8	3.8	15.6	2.0	0.2
		Option 6	5.8	3.8	15.6	2.0	0.2
Dairy Large CAFOs							
	Large 1	Option 1	7,592.7	2,227.4	217.1	71,757.5	3,048.3
		Options 2-4,7	8,976.9	12,147.8	850.7	151,837.6	7,698.6
		Option 5A	567.9	1,013.2	184.1	2,397.5	465.3
		Option 6	8,976.9	12,147.8	850.7	151,837.6	7,698.6
Dairy Medium CAFOs							
	Medium 3	Option 1	11.7	18.4	8.8	52.4	50.9
		Options 2-4,7	69.8	576.9	41.8	172.4	97.7
		Option 5A	69.8	576.8	41.8	172.4	98.2
		Option 6	69.8	576.9	41.8	172.4	97.7

Table 4.1-3 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Medium CAFOs (cont.)							
	Medium 2	Option 1	182.8	276.4	209.8	480.1	437.0
		Options 2-4,7	177.4	2,669.7	284.5	363.1	444.5
		Option 5A	177.4	2,292.3	284.5	268.0	447.4
		Option 6	177.4	2,669.7	284.5	363.1	444.5
	Medium 1	Option 1	11.3	26.3	29.4	9.0	6.5
		Options 2-4,7	149.8	2,911.7	291.2	172.6	139.8
		Option 5A	149.8	2,911.7	291.2	172.6	139.8
		Option 6	149.8	2,911.7	291.2	172.6	139.8
Heifer Large CAFOs							
	Large 1	Option 1	7.0	N/A	N/A	47.0	N/A
		Options 2-4,7	282.2	N/A	N/A	527.0	N/A
		Option 5A	286.0	N/A	N/A	527.0	N/A
		Option 6	282.0	N/A	N/A	527.0	N/A
Heifer Medium CAFOs							
	Medium 3	Option 1	0.4	N/A	0.3	5.0	N/A
		Options 2-4,7	5.3	N/A	2.9	5.0	N/A
		Option 5A	5.2	N/A	2.8	2.7	N/A
		Option 6	5.3	N/A	2.9	5.0	N/A
	Medium 2	Option 1	0.9	N/A	0.7	9.3	N/A
		Options 2-4,7	8.8	N/A	5.3	9.3	N/A
		Option 5A	8.8	N/A	5.3	2.3	N/A
		Option 6	8.8	N/A	5.3	9.3	N/A
	Medium 1	Option 1	0.4	N/A	5.6	4.3	N/A
		Options 2-4,7	2.3	N/A	27.2	4.3	N/A
		Option 5A	2.3	N/A	27.2	4.3	N/A
		Option 6	2.3	N/A	27.2	4.3	N/A
Swine - Grow-Finish Large CAFOs							
	Large 2	Option 1	377.6	572.8	387.6	N/A	N/A
		Options 2-4,7	1,616.3	16,664.0	2,540.5	N/A	N/A
		Option 5	818.4	8,624.7	885.1	N/A	N/A
		Option 6	1,616.3	16,664.0	2,038.9	N/A	N/A
	Large 1	Option 1	31.0	103.6	145.1	N/A	N/A
		Options 2-4,7	186.2	4,693.2	1,394.3	N/A	N/A
		Option 5	64.8	2,640.2	497.5	N/A	N/A
		Option 6	186.2	4,693.2	1,394.3	N/A	N/A

Table 4.1-3 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Swine-Grow Finish Medium CAFOs							
	Medium 3	Option 1	N/A	2.8	8.2	N/A	N/A
		Options 2-4,7	N/A	147.0	86.2	N/A	N/A
		Option 5	N/A	91.9	34.4	N/A	N/A
		Option 6	N/A	147.0	86.2	N/A	N/A
	Medium 2	Option 1	N/A	1.0	6.2	N/A	N/A
		Options 2-4,7	N/A	64.7	77.0	N/A	N/A
		Option 5	N/A	44.1	36.0	N/A	N/A
		Option 6	N/A	64.7	77.0	N/A	N/A
	Medium 1	Option 1	N/A	1.2	7.7	N/A	N/A
		Options 2-4,7	N/A	80.0	95.3	N/A	N/A
		Option 5	N/A	54.5	44.6	N/A	N/A
		Option 6	N/A	80.0	95.3	N/A	N/A
Swine - Farrow-to-Finish Large CAFOs							
	Large 2	Option 1	148.1	598.7	1,207.9	N/A	N/A
		Options 2-4,7	733.8	23,594.7	9,639.0	N/A	N/A
		Option 5	316.9	14,103.3	4,017.2	N/A	N/A
		Option 6	733.8	23,594.7	7,688.6	N/A	N/A
	Large 1	Option 1	32.1	38.3	202.4	N/A	N/A
		Option 2	220.1	2,016.0	2,241.3	N/A	N/A
		Option 5	64.6	1,092.3	718.3	N/A	N/A
		Option 6	220.1	2,016.0	2,241.3	N/A	N/A
Swine - Farrow-to-Finish Medium CAFOs							
	Medium 3	Option 1	N/A	1.2	9.2	N/A	N/A
		Options 2-4,7	N/A	80.3	122.4	N/A	N/A
		Option 5	N/A	43.5	41.2	N/A	N/A
		Option 6	N/A	80.3	122.4	N/A	N/A
	Medium 2	Option 1	N/A	1.0	9.6	N/A	N/A
		Options 2-4,7	N/A	71.3	139.0	N/A	N/A
		Option 5	N/A	40.5	50.8	N/A	N/A
		Option 6	N/A	71.3	139.0	N/A	N/A
	Medium 1	Option 1	N/A	1.1	10.5	N/A	N/A
		Options 2-4,7	N/A	77.5	151.6	N/A	N/A
		Option 5	N/A	44.0	55.4	N/A	N/A
		Option 6	N/A	77.5	151.6	N/A	N/A

Table 4.1-3 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Broilers Large CAFOs							
	Large 2	Option 1	N/A	317.1	N/A	N/A	841.7
		Options 2-4,7	N/A	3,038.0	N/A	N/A	2,452.3
		Option 5	N/A	3,038.0	N/A	N/A	2,452.3
		Option 6	N/A	3,038.0	N/A	N/A	2,452.3
	Large 1	Option 1	N/A	181.7	N/A	N/A	400.6
		Options 2-4,7	N/A	1,945.3	N/A	N/A	1,263.2
		Option 5	N/A	1,945.3	N/A	N/A	1,263.2
		Option 6	N/A	1,945.3	N/A	N/A	1,263.2
Broilers Medium CAFOs							
	Medium 3	Option 1	N/A	20.0	N/A	N/A	43.0
		Options 2-4,7	N/A	248.0	N/A	N/A	153.0
		Option 5	N/A	248.0	N/A	N/A	153.0
		Option 6	N/A	248.0	N/A	N/A	153.0
	Medium 2	Option 1	N/A	14.0	N/A	N/A	28.0
		Options 2-4,7	N/A	181.0	N/A	N/A	100.0
		Option 5	N/A	181.0	N/A	N/A	100.0
		Option 6	N/A	181.0	N/A	N/A	100.0
	Medium 1	Option 1	N/A	8.0	N/A	N/A	13.0
		Options 2-4,7	N/A	105.0	N/A	N/A	50.0
		Option 5	N/A	105.0	N/A	N/A	50.0
		Option 6	N/A	105.0	N/A	N/A	50.0
Layers - Dry Large CAFOs							
	Large 2	Option 1	N/A	N/A	456.4	N/A	119.9
		Options 2-4,7	N/A	N/A	1,231.3	N/A	448.2
		Option 5	N/A	N/A	1,231.3	N/A	448.2
		Option 6	N/A	N/A	1,231.3	N/A	448.2
	Large 1	Option 1	N/A	N/A	634.4	N/A	257.0
		Options 2-4,7	N/A	N/A	1,687.2	N/A	911.5
		Option 5	N/A	N/A	1,687.2	N/A	911.5
		Option 6	N/A	N/A	1,687.2	N/A	911.5
Layers - Dry Medium CAFOs							
	Medium 3	Option 1	N/A	N/A	0.4	N/A	0.2
		Options 2-4,7	N/A	N/A	1.0	N/A	0.7
		Option 5	N/A	N/A	1.0	N/A	0.7
		Option 6	N/A	N/A	1.0	N/A	0.7

Table 4.1-3 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Layers - Dry Medium CAFOs (cont.)							
	Medium 2	Option 1	N/A	N/A	1.3	N/A	0.8
		Options 2-4,7	N/A	N/A	3.5	N/A	2.8
		Option 5	N/A	N/A	3.5	N/A	2.8
		Option 6	N/A	N/A	3.5	N/A	2.8
	Medium 1	Option 1	N/A	N/A	1.8	N/A	1.5
		Options 2-4,7	N/A	N/A	4.2	N/A	4.3
		Option 5	N/A	N/A	4.2	N/A	4.3
		Option 6	N/A	N/A	4.2	N/A	4.3
Layers - Wet Large CAFOs							
	Large 1	Option 1	N/A	N/A	N/A	N/A	582.2
		Options 2-4,7	N/A	N/A	N/A	N/A	1,947.6
		Option 5	N/A	N/A	N/A	N/A	791.4
		Option 6	N/A	N/A	N/A	N/A	1,947.6
Layers - Wet Medium CAFOs							
	Medium 3	Option 1	N/A	N/A	N/A	N/A	1.7
		Options 2-4,7	N/A	N/A	N/A	N/A	5.2
		Option 5	N/A	N/A	N/A	N/A	1.9
		Option 6	N/A	N/A	N/A	N/A	5.0
Turkey Large CAFOs							
	Large 1	Option 1	N/A	157.0	267.0	N/A	N/A
		Options 2-4,7	N/A	2,396.5	825.0	N/A	N/A
		Option 5	N/A	2,396.5	825.0	N/A	N/A
		Option 6	N/A	2,396.5	825.0	N/A	N/A
Turkey Medium CAFOs							
	Medium 3	Option 1	N/A	1.5	1.0	N/A	N/A
		Options 2-4,7	N/A	18.2	2.7	N/A	N/A
		Option 5	N/A	18.2	2.7	N/A	N/A
		Option 6	N/A	18.2	2.7	N/A	N/A
	Medium 2	Option 1	N/A	1.8	1.1	N/A	N/A
		Options 2-4,7	N/A	22.3	3.2	N/A	N/A
		Option 5	N/A	22.3	3.2	N/A	N/A
		Option 6	N/A	22.3	3.2	N/A	N/A
	Medium 1	Option 1	N/A	1.9	1.2	N/A	N/A
		Options 2-4,7	N/A	24.4	3.5	N/A	N/A
		Option 5	N/A	24.4	3.5	N/A	N/A
		Option 6	N/A	24.0	4.0	N/A	N/A

N/A - Not Applicable.

Table 4.1-4

Industry-Level Incremental NO_x Emissions above Option 1 from Transportation of Manure Off Site by Regulatory Option (lbs/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Option 1	11,076.5	1,148.9	7,033.6	15,081.1	N/A
		Options 2-4,7	206,875.1	50,428.9	237,277.7	179,345.1	N/A
		Option 5A	206,875.2	50,392.6	237,277.7	179,233.1	N/A
		Option 6	206,875.1	50,428.9	237,277.7	179,345.1	N/A
	Large 1	Option 1	1,212.7	288.7	2,692.3	18,900.1	N/A
		Options 2-4,7	33,060.0	4,271.6	33,508.8	13,123.2	N/A
		Option 5A	33,059.5	4,263.4	33,508.8	13,123.2	N/A
		Option 6	33,060.0	4,271.6	33,508.8	13,123.2	N/A
Beef Medium CAFOs							
	Medium 3	Option 1	10.7	0.4	22.7	2.6	0.2
		Options 2-4,7	93.6	29.5	166.4	42.3	3.4
		Option 5A	93.6	29.5	166.4	42.3	3.4
		Option 6	93.6	29.5	166.4	42.3	3.4
	Medium 2	Option 1	15.8	1.1	45.9	2.6	0.2
		Options 2-4,7	94.3	60.2	254.7	31.1	3.0
		Option 5A	94.3	60.2	254.7	31.1	3.0
		Option 6	94.3	60.2	254.7	31.1	3.0
	Medium 1	Option 1	28.8	9.2	84.0	6.9	2.2
		Options 2-4,7	125.7	77.6	334.4	41.7	5.0
		Option 5A	125.7	77.6	334.4	41.7	5.0
		Option 6	125.7	77.6	334.4	41.7	5.0
Dairy Large CAFOs							
	Large 1	Option 1	152,432.3	44,735.2	4,421.1	1,438,025.9	61,057.1
		Options 2-4,7	181,171.3	244,437.1	17,382.0	3,042,796.0	154,340.7
		Option 5A	12,354.0	21,488.7	3,986.0	51,461.2	9,552.2
		Option 6	181,171.3	244,437.1	17,382.0	3,042,796.0	154,340.7
Dairy Medium CAFOs							
	Medium 3	Option 1	255.4	389.3	192.5	1,082.4	1,027.8
		Options 2-4,7	1,458.1	11,800.2	886.7	3,558.7	1,988.3
		Option 5A	1,458.1	11,798.0	886.7	3,558.7	1,998.3
		Option 6	1,458.1	11,800.2	886.7	3,558.7	1,988.3

Table 4.1-4 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Medium CAFOs (cont.)							
	Medium 2	Option 1	3,696.8	5,625.7	4,306.1	9,633.7	8,761.1
		Options 2-4,7	3,641.7	54,272.3	5,956.1	7,342.7	8,943.0
		Option 5A	3,641.7	46,723.5	5,956.1	5,440.3	9,000.1
		Option 6	3,641.7	54,272.3	5,956.1	7,342.7	8,943.0
	Medium 1	Option 1	247.6	576.4	644.5	196.5	143.2
		Options 2-4,7	3,109.9	59,402.7	6,140.3	3,559.2	2,868.8
		Option 5A	3,109.9	59,402.7	6,140.3	3,559.2	2,868.8
		Option 6	3,109.9	59,402.7	6,140.3	3,559.2	2,868.8
Heifer Large CAFOs							
	Large 1	Option 1	148.0	N/A	N/A	1,024.0	N/A
		Options 2-4,7	6,055.8	N/A	N/A	11,015.5	N/A
		Option 5A	6,134.0	N/A	N/A	11,051.0	N/A
		Option 6	6,056.0	N/A	N/A	11,016.0	N/A
Heifer Medium CAFOs							
	Medium 3	Option 1	8.4	N/A	6.6	104.5	N/A
		Options 2-4,7	113.6	N/A	61.0	104.5	N/A
		Option 5A	111.4	N/A	58.4	54.9	N/A
		Option 6	113.6	N/A	61.0	104.5	N/A
	Medium 2	Option 1	20.8	N/A	16.2	192.5	N/A
		Options 2-4,7	188.1	N/A	111.8	192.5	N/A
		Option 5A	188.1	N/A	111.8	45.9	N/A
		Option 6	188.1	N/A	111.8	192.5	N/A
	Medium 1	Option 1	8.0	N/A	122.6	89.5	N/A
		Options 2-4,7	50.1	N/A	579.6	89.5	N/A
		Option 5A	50.1	N/A	579.6	90.0	N/A
		Option 6	50.1	N/A	579.6	89.5	N/A
Swine - Grow-Finish Large CAFOs							
	Large 2	Option 1	7,552.1	11,455.8	7,752.8	N/A	N/A
		Options 2-4,7	32,326.6	333,279.4	50,809.3	N/A	N/A
		Option 5	16,367.6	172,493.4	17,701.3	N/A	N/A
		Option 6	32,326.6	333,279.4	40,779.0	N/A	N/A
	Large 1	Option 1	619.5	2,072.5	2,902.5	N/A	N/A
		Options 2-4,7	3,723.7	93,864.4	27,885.4	N/A	N/A
		Option 5	1,296.1	52,803.4	9,950.6	N/A	N/A
		Option 6	3,723.7	93,864.4	27,885.4	N/A	N/A

Table 4.1-4 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow-Finish Medium CAFOs							
	Medium 3	Option 1	N/A	55.4	163.6	N/A	N/A
		Options 2-4,7	N/A	2,939.5	1,723.6	N/A	N/A
		Option 5	N/A	1,837.3	688.2	N/A	N/A
		Option 6	N/A	2,939.5	1,723.6	N/A	N/A
	Medium 2	Option 1	N/A	19.4	124.2	N/A	N/A
		Options 2-4,7	N/A	1,294.1	1,539.8	N/A	N/A
		Option 5	N/A	882.6	720.7	N/A	N/A
		Option 6	N/A	1,294.1	1,539.8	N/A	N/A
	Medium 1	Option 1	N/A	24.0	153.8	N/A	N/A
		Options 2-4,7	N/A	1,600.0	1,906.6	N/A	N/A
		Option 5	N/A	1,090.1	892.7	N/A	N/A
		Option 6	N/A	1,600.0	1,906.6	N/A	N/A
Swine - Farrow-to-Finish Large CAFOs							
	Large 2	Option 1	2,962.8	11,974.5	24,157.7	N/A	N/A
		Options 2-4,7	14,677.0	471,894.9	192,780.5	N/A	N/A
		Option 5	6,338.5	282,066.2	80,344.4	N/A	N/A
		Option 6	14,677.0	471,894.9	153,772.3	N/A	N/A
	Large 1	Option 1	641.1	766.8	4,047.2	N/A	N/A
		Options 2-4,7	4,402.7	40,319.7	44,825.8	N/A	N/A
		Option 5	1,292.2	21,845.4	14,365.6	N/A	N/A
		Option 6	4,402.7	40,319.7	44,825.8	N/A	N/A
Swine - Farrow-to-Finish Medium CAFOs							
	Medium 3	Option 1	N/A	24.3	184.5	N/A	N/A
		Options 2-4,7	N/A	1,605.4	2,447.1	N/A	N/A
		Option 5	N/A	869.2	823.5	N/A	N/A
		Option 6	N/A	1,605.4	2,447.1	N/A	N/A
	Medium 2	Option 1	N/A	19.3	192.1	N/A	N/A
		Options 2-4,7	N/A	1,426.4	2,779.5	N/A	N/A
		Option 5	N/A	810.8	1,015.1	N/A	N/A
		Option 6	N/A	1,426.4	2,779.5	N/A	N/A
	Medium 1	Option 1	N/A	21.0	209.5	N/A	N/A
		Options 2-4,7	N/A	1,550.7	3,031.2	N/A	N/A
		Option 5	N/A	880.8	1,107.0	N/A	N/A
		Option 6	N/A	1,550.7	3,031.2	N/A	N/A

Table 4.1-4 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Broilers Large CAFOs							
	Large 2	Option 1	N/A	6,949.1	N/A	N/A	18,447.8
		Options 2-4,7	N/A	66,582.3	N/A	N/A	53,745.7
		Option 5	N/A	66,582.3	N/A	N/A	53,745.7
		Option 6	N/A	66,582.3	N/A	N/A	53,745.7
	Large 1	Option 1	N/A	3,981.6	N/A	N/A	8,778.9
		Options 2-4,7	N/A	42,633.8	N/A	N/A	27,685.5
		Option 5	N/A	42,633.8	N/A	N/A	27,685.5
		Option 6	N/A	42,633.8	N/A	N/A	27,685.5
Broilers Medium CAFOs							
	Medium 3	Option 1	N/A	433.5	N/A	N/A	948.3
		Options 2-4,7	N/A	5,426.9	N/A	N/A	3,342.8
		Option 5	N/A	5,426.9	N/A	N/A	3,342.8
		Option 6	N/A	5,426.9	N/A	N/A	3,342.8
	Medium 2	Option 1	N/A	316.1	N/A	N/A	620.6
		Options 2-4,7	N/A	3,956.4	N/A	N/A	2,187.7
		Option 5	N/A	3,956.4	N/A	N/A	2,187.7
		Option 6	N/A	3,956.4	N/A	N/A	2,187.7
	Medium 1	Option 1	N/A	169.0	N/A	N/A	293.0
		Options 2-4,7	N/A	2,306.1	N/A	N/A	1,103.8
		Option 5	N/A	2,306.1	N/A	N/A	1,103.8
		Option 6	N/A	2,306.1	N/A	N/A	1,103.8
Layers - Dry Large CAFOs							
	Large 2	Option 1	N/A	N/A	10,003.7	N/A	2,627.4
		Options 2-4,7	N/A	N/A	26,986.7	N/A	9,822.7
		Option 5	N/A	N/A	26,986.7	N/A	9,822.7
		Option 6	N/A	N/A	26,986.7	N/A	9,822.7
	Large 1	Option 1	N/A	N/A	13,904.2	N/A	5,641.4
		Options 2-4,7	N/A	N/A	36,978.4	N/A	19,976.7
		Option 5	N/A	N/A	36,978.4	N/A	19,976.7
		Option 6	N/A	N/A	36,978.4	N/A	19,976.7
Layers - Dry Medium CAFOs							
	Medium 3	Option 1	N/A	N/A	8.3	N/A	4.5
		Options 2-4,7	N/A	N/A	22.0	N/A	16.1
		Option 5	N/A	N/A	22.0	N/A	16.1
		Option 6	N/A	N/A	22.0	N/A	16.1

Table 4.1-4 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Layers - Dry Medium CAFOs (cont.)							
	Medium 2	Option 1	N/A	N/A	29.1	N/A	17.5
		Options 2-4,7	N/A	N/A	77.4	N/A	62.0
		Option 5	N/A	N/A	77.4	N/A	62.0
		Option 6	N/A	N/A	77.4	N/A	62.0
	Medium 1	Option 1	N/A	N/A	40.3	N/A	32.1
		Options 2-4,7	N/A	N/A	91.7	N/A	95.1
		Option 5	N/A	N/A	91.7	N/A	95.1
		Option 6	N/A	N/A	91.7	N/A	95.1
Layers - Wet Large CAFOs							
	Large 1	Option 1	N/A	N/A	N/A	N/A	11,644.5
		Options 2-4,7	N/A	N/A	N/A	N/A	38,951.5
		Option 5	N/A	N/A	N/A	N/A	15,828.7
		Option 6	N/A	N/A	N/A	N/A	38,951.5
Layers - Wet Medium CAFOs							
	Medium 3	Option 1	N/A	N/A	N/A	N/A	34.5
		Options 2-4,7	N/A	N/A	N/A	N/A	103.3
		Option 5	N/A	N/A	N/A	N/A	37.9
		Option 6	N/A	N/A	N/A	N/A	103.3
Turkey Large CAFOs							
	Large 1	Option 1	N/A	3,441.2	5,851.4	N/A	N/A
		Options 2-4,7	N/A	52,523.2	18,080.5	N/A	N/A
		Option 5	N/A	52,523.2	18,080.5	N/A	N/A
		Option 6	N/A	52,523.2	18,080.5	N/A	N/A
Turkey Medium CAFOs							
	Medium 3	Option 1	N/A	31.9	21.5	N/A	N/A
		Options 2-4,7	N/A	399.6	60.2	N/A	N/A
		Option 5	N/A	399.6	60.2	N/A	N/A
		Option 6	N/A	399.6	60.2	N/A	N/A
	Medium 2	Option 1	N/A	38.9	24.9	N/A	N/A
		Options 2-4,7	N/A	489.3	71.1	N/A	N/A
		Option 5	N/A	489.3	71.1	N/A	N/A
		Option 6	N/A	489.3	71.1	N/A	N/A
	Medium 1	Option 1	N/A	42.4	26.8	N/A	N/A
		Options 2-4,7	N/A	533.8	76.7	N/A	N/A
		Option 5	N/A	533.8	76.7	N/A	N/A
		Option 6	N/A	533.8	76.7	N/A	N/A

N/A - Not Applicable.

Table 4.1-5

Industry-Level Incremental PM Emissions above Option 1 from Transportation of Manure Off Site by Regulatory Option (lbs/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Option 1	401.0	36.4	254.7	546.0	N/A
		Options 2-4,7	7,084.5	1,586.2	7,958.2	5,705.5	N/A
		Option 5A	7,084.5	1,584.9	7,958.2	5,701.5	N/A
		Option 6	7,084.5	1,586.2	7,958.2	5,705.5	N/A
	Large 1	Option 1	43.9	9.1	87.3	596.0	N/A
		Options 2-4,7	1,171.0	137.8	1,166.5	438.2	N/A
		Option 5A	1,170.6	137.5	1,166.5	438.2	N/A
		Option 6	1,171.0	137.8	1,166.5	438.2	N/A
Beef Medium CAFOs							
	Medium 3	Option 1	0.4	0.0	0.8	0.1	0.0
		Options 2-4,7	3.3	1.0	5.8	1.4	0.1
		Option 5A	3.3	1.0	5.8	1.4	0.1
		Option 6	3.3	1.0	5.8	1.4	0.1
	Medium 2	Option 1	0.6	0.0	1.7	0.1	0.0
		Options 2-4,7	3.3	2.0	8.9	1.0	0.1
		Option 5A	3.3	2.0	8.9	1.0	0.1
		Option 6	3.3	2.0	8.9	1.0	0.1
	Medium 1	Option 1	1.0	0.3	3.0	0.2	0.1
		Options 2-4,7	4.4	2.5	11.7	1.4	0.2
		Option 5A	4.4	2.5	11.7	1.4	0.2
		Option 6	4.4	2.5	11.7	1.4	0.2
Dairy Large CAFOs							
	Large 1	Option 1	4,767.2	1,400.0	141.9	44,821.3	1,901.2
		Options 2-4,7	5,721.8	7,677.3	5,614.0	94,837.3	4,814.1
		Option 5A	442.3	739.4	141.7	1,804.9	311.1
		Option 6	5,721.8	7,677.3	5,614.0	94,837.3	4,814.1
Dairy Medium CAFOs							
	Medium 3	Option 1	9.2	13.3	7.0	35.6	32.5
		Options 2-4,7	48.9	381.8	30.5	117.1	63.7
		Option 5A	48.9	381.8	30.5	117.1	64.0
		Option 6	48.9	381.8	30.5	117.1	63.7

Table 4.1-5 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Medium CAFOs (cont.)							
	Medium 2	Option 1	117.2	180.4	140.2	301.0	273.3
		Options 2-4,7	118.6	1,736.9	200.6	232.8	280.8
		Option 5A	118.6	1,502.5	200.6	173.7	282.6
		Option 6	118.6	1,736.9	200.6	232.8	280.8
	Medium 1	Option 1	9.0	20.9	23.3	7.1	5.2
		Options 2-4,7	103.3	1,913.4	209.3	116.9	93.4
		Option 5A	103.3	1,913.4	209.3	116.9	93.4
		Option 6	103.3	1,913.4	209.3	116.9	93.4
Heifer Large CAFOs							
	Large 1	Option 1	5.0	N/A	N/A	37.0	N/A
		Options 2-4,7	212.4	N/A	N/A	370.0	N/A
		Option 5A	215.0	N/A	N/A	370.0	N/A
		Option 6	212.4	N/A	N/A	370.0	N/A
Heifer Medium CAFOs							
	Medium 3	Option 1	0.3	N/A	0.2	3.5	N/A
		Options 2-4,7	4.0	N/A	2.1	3.5	N/A
		Option 5A	3.9	N/A	2.0	1.8	N/A
		Option 6	4.0	N/A	2.1	3.5	N/A
	Medium 2	Option 1	0.8	N/A	0.6	6.4	N/A
		Options 2-4,7	6.6	N/A	3.9	6.4	N/A
		Option 5A	6.6	N/A	3.9	1.5	N/A
		Option 6	6.6	N/A	3.9	6.4	N/A
	Medium 1	Option 1	0.3	N/A	4.4	2.9	N/A
		Options 2-4,7	1.8	N/A	20.0	2.9	N/A
		Option 5A	1.8	N/A	20.0	2.9	N/A
		Option 6	1.8	N/A	20.0	2.9	N/A
Swine - Grow-Finish Large CAFOs							
	Large 2	Option 1	234.5	355.7	240.7	N/A	N/A
		Options 2-4,7	1,003.8	10,348.6	1,577.7	N/A	N/A
		Option 5	508.2	5,356.0	549.6	N/A	N/A
		Option 6	1,003.8	10,348.6	1,266.2	N/A	N/A
	Large 1	Option 1	19.2	64.4	90.1	N/A	N/A
		Options 2-4,7	115.6	2,914.6	865.9	N/A	N/A
		Option 5	40.2	1,639.6	309.0	N/A	N/A
		Option 6	115.6	2,914.6	865.9	N/A	N/A

Table 4.1-5 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow-Finish Medium CAFOs							
	Medium 3	Option 1	N/A	1.7	5.1	N/A	N/A
		Options 2-4,7	N/A	91.3	53.5	N/A	N/A
		Option 5	N/A	57.0	21.4	N/A	N/A
		Option 6	N/A	91.3	53.5	N/A	N/A
	Medium 2	Option 1	N/A	0.6	3.9	N/A	N/A
		Options 2-4,7	N/A	40.2	47.8	N/A	N/A
		Option 5	N/A	27.4	22.4	N/A	N/A
		Option 6	N/A	40.2	47.8	N/A	N/A
	Medium 1	Option 1	N/A	0.7	4.8	N/A	N/A
		Options 2-4,7	N/A	49.7	59.2	N/A	N/A
		Option 5	N/A	33.8	27.7	N/A	N/A
		Option 6	N/A	49.7	59.2	N/A	N/A
Swine - Farrow-to-Finish Large CAFOs							
	Large 2	Option 1	92.0	371.8	750.1	N/A	N/A
		Options 2-4,7	455.7	14,652.7	5,986.0	N/A	N/A
		Option 5	196.8	8,758.4	2,494.8	N/A	N/A
		Option 6	455.7	14,652.7	4,774.7	N/A	N/A
	Large 1	Option 1	19.9	23.8	125.7	N/A	N/A
		Options 2-4,7	136.7	1,252.0	1,391.9	N/A	N/A
		Option 5	40.1	678.3	446.1	N/A	N/A
		Option 6	136.7	1,252.0	1,391.9	N/A	N/A
Swine - Farrow-to-Finish Medium CAFOs							
	Medium 3	Option 1	N/A	0.8	5.7	N/A	N/A
		Options 2-4,7	N/A	49.8	76.0	N/A	N/A
		Option 5	N/A	27.0	25.6	N/A	N/A
		Option 6	N/A	49.8	76.0	N/A	N/A
	Medium 2	Option 1	N/A	0.6	6.0	N/A	N/A
		Options 2-4,7	N/A	44.3	86.3	N/A	N/A
		Option 5	N/A	25.2	31.5	N/A	N/A
		Option 6	N/A	44.3	86.3	N/A	N/A
	Medium 1	Option 1	N/A	0.7	6.5	N/A	N/A
		Options 2-4,7	N/A	48.2	94.1	N/A	N/A
		Option 5	N/A	27.4	34.4	N/A	N/A
		Option 6	N/A	48.2	94.1	N/A	N/A

Table 4.1-5 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Broilers Large CAFOs							
	Large 2	Option 1	N/A	251.6	N/A	N/A	667.9
		Options 2-4,7	N/A	2,410.7	N/A	N/A	1,945.9
		Option 5	N/A	2,410.7	N/A	N/A	1,945.9
		Option 6	N/A	2,410.7	N/A	N/A	1,945.9
	Large 1	Option 1	N/A	144.2	N/A	N/A	317.9
		Options 2-4,7	N/A	1,543.6	N/A	N/A	1,002.4
		Option 5	N/A	1,543.6	N/A	N/A	1,002.4
		Option 6	N/A	1,543.6	N/A	N/A	1,002.4
Broilers Medium CAFOs							
	Medium 3	Option 1	N/A	15.7	N/A	N/A	34.3
		Options 2-4,7	N/A	196.5	N/A	N/A	121.0
		Option 5	N/A	196.5	N/A	N/A	121.0
		Option 6	N/A	196.5	N/A	N/A	121.0
	Medium 2	Option 1	N/A	11.4	N/A	N/A	22.5
		Options 2-4,7	N/A	143.2	N/A	N/A	79.2
		Option 5	N/A	143.2	N/A	N/A	79.2
		Option 6	N/A	143.2	N/A	N/A	79.2
	Medium 1	Option 1	N/A	6.1	N/A	N/A	10.6
		Options 2-4,7	N/A	83.5	N/A	N/A	40.0
		Option 5	N/A	83.5	N/A	N/A	40.0
		Option 6	N/A	83.5	N/A	N/A	40.0
Layers - Dry Large CAFOs							
	Large 2	Option 1	N/A	N/A	362.2	N/A	95.1
		Options 2-4,7	N/A	N/A	977.1	N/A	355.6
		Option 5	N/A	N/A	977.1	N/A	355.6
		Option 6	N/A	N/A	977.1	N/A	355.6
	Large 1	Option 1	N/A	N/A	503.4	N/A	204.3
		Options 2-4,7	N/A	N/A	1,338.8	N/A	723.3
		Option 5	N/A	N/A	1,338.8	N/A	723.3
		Option 6	N/A	N/A	1,338.8	N/A	723.3
Layers - Dry Medium CAFOs							
	Medium 3	Option 1	N/A	N/A	0.3	N/A	0.2
		Options 2-4,7	N/A	N/A	0.8	N/A	0.6
		Option 5	N/A	N/A	0.8	N/A	0.6
		Option 6	N/A	N/A	0.8	N/A	0.6

Table 4.1-5 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Layers - Dry Medium CAFOs (cont.)							
	Medium 2	Option 1	N/A	N/A	1.1	N/A	0.6
		Options 2-4,7	N/A	N/A	2.8	N/A	2.2
		Option 5	N/A	N/A	2.8	N/A	2.2
		Option 6	N/A	N/A	2.8	N/A	2.2
	Medium 1	Option 1	N/A	N/A	1.5	N/A	1.2
		Options 2-4,7	N/A	N/A	3.3	N/A	3.4
		Option 5	N/A	N/A	3.3	N/A	3.4
		Option 6	N/A	N/A	3.3	N/A	3.4
Layers - Wet Large CAFOs							
	Large 1	Option 1	N/A	N/A	N/A	N/A	361.6
		Options 2-4,7	N/A	N/A	N/A	N/A	1,209.5
		Option 5	N/A	N/A	N/A	N/A	491.5
		Option 6	N/A	N/A	N/A	N/A	1,209.5
Layers - Wet Medium CAFOs							
	Medium 3	Option 1	N/A	N/A	N/A	N/A	1.1
		Options 2-4,7	N/A	N/A	N/A	N/A	3.2
		Option 5	N/A	N/A	N/A	N/A	1.2
		Option 6	N/A	N/A	N/A	N/A	3.2
Turkey Large CAFOs							
	Large 1	Option 1	N/A	124.6	211.9	N/A	N/A
		Options 2-4,7	N/A	1,901.7	654.6	N/A	N/A
		Option 5	N/A	1,901.7	654.6	N/A	N/A
		Option 6	N/A	1,901.7	654.6	N/A	N/A
Turkey Medium CAFOs							
	Medium 3	Option 1	N/A	1.2	0.8	N/A	N/A
		Options 2-4,7	N/A	14.5	2.2	N/A	N/A
		Option 5	N/A	14.5	2.2	N/A	N/A
		Option 6	N/A	14.5	2.2	N/A	N/A
	Medium 2	Option 1	N/A	1.4	0.9	N/A	N/A
		Options 2-4,7	N/A	17.7	2.6	N/A	N/A
		Option 5	N/A	17.7	2.6	N/A	N/A
		Option 6	N/A	17.7	2.6	N/A	N/A
	Medium 1	Option 1	N/A	1.5	1.0	N/A	N/A
		Options 2-4,7	N/A	19.3	2.8	N/A	N/A
		Option 5	N/A	19.3	2.8	N/A	N/A
		Option 6	N/A	19.3	2.8	N/A	N/A

N/A- Not Applicable.

Table 4.1-6

Industry-Level Incremental CO Emissions above Option 1 from Transportation of Manure Off Site by Regulatory Option (lbs/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Option 1	2,746.9	321.2	1,744.3	3,740.0	N/A
		Options 2-4,7	54,112.9	14,165.5	63,225.0	49,932.6	N/A
		Option 5A	54,112.9	14,156.5	63,225.0	49,904.9	N/A
		Option 6	54,112.9	14,165.5	63,225.0	49,932.6	N/A
	Large 1	Option 1	300.7	80.8	738.2	5,298.9	N/A
		Options 2-4,7	8,381.0	1,176.2	8,633.3	3,510.1	N/A
		Option 5A	8,381.2	1,174.2	8,633.3	3,510.1	N/A
		Option 6	8,381.0	1,176.2	8,633.3	3,510.1	N/A
Beef Medium CAFOs							
	Medium 3	Option 1	2.6	0.1	5.6	0.6	0.0
		Options 2-4,7	23.9	8.0	43.0	11.3	0.9
		Option 5A	23.9	8.0	43.0	11.3	0.9
		Option 6	23.9	8.0	43.0	11.3	0.9
	Medium 2	Option 1	3.9	0.3	11.4	0.6	0.1
		Options 2-4,7	24.0	16.3	65.7	8.3	0.8
		Option 5A	24.0	16.3	65.7	8.3	0.8
		Option 6	24.0	16.3	65.7	8.3	0.8
	Medium 1	Option 1	7.1	2.5	20.8	1.8	0.6
		Options 2-4,7	32.0	21.1	86.0	11.1	1.4
		Option 5A	32.0	21.1	86.0	11.1	1.4
		Option 6	32.0	21.1	86.0	11.1	1.4
Dairy Large CAFOs							
	Large 1	Option 1	43,008.3	12,615.2	1,222.1	406,787.8	17,284.5
		Options 2-4,7	50,730.4	68,740.9	4,781.1	860,760.9	43,635.4
		Option 5A	3,098.5	5,596.5	1,006.3	13,165.7	2,609.8
		Option 6	50,730.4	68,740.9	4,781.1	860,760.9	43,635.4
Dairy Medium CAFOs							
	Medium 3	Option 1	63.3	101.9	47.7	293.0	287.8
		Options 2-4,7	388.4	3,240.8	230.8	964.1	550.2
		Option 5A	388.4	3,240.3	230.8	964.1	553.1
		Option 6	388.4	3,240.8	230.8	964.1	550.2

Table 4.1-6 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Medium CAFOs (cont.)							
	Medium 2	Option 1	1,032.0	1,556.5	1,176.6	2,719.9	2,476.8
		Options 2-4,7	995.0	15,038.4	1,581.2	2,050.2	2,515.4
		Option 5A	995.0	12,897.2	1,581.2	1,510.5	2,531.6
		Option 6	995.0	15,038.4	1,581.2	2,050.2	2,515.4
	Medium 1	Option 1	61.4	142.9	159.8	48.7	35.5
		Options 2-4,7	835.4	16,375.1	1,613.1	965.6	783.8
		Option 5A	835.4	16,375.1	1,613.1	965.6	783.8
		Option 6	835.4	16,375.1	1,613.1	965.6	783.8
Heifer Large CAFOs							
	Large 1	Option 1	37.0	N/A	N/A	254.0	N/A
		Options 2-4,7	1,549.6	N/A	N/A	2,931.2	N/A
		Option 5A	1,569.0	N/A	N/A	2,931.0	N/A
		Option 6	1,549.6	N/A	N/A	2,931.2	N/A
Heifer Medium CAFOs							
	Medium 3	Option 1	2.1	N/A	1.6	28.0	N/A
		Options 2-4,7	29.2	N/A	15.9	28.0	N/A
		Option 5A	28.7	N/A	15.2	14.9	N/A
		Option 6	29.2	N/A	15.9	28.0	N/A
	Medium 2	Option 1	5.1	N/A	4.0	51.8	N/A
		Options 2-4,7	48.2	N/A	29.1	51.8	N/A
		Option 5A	48.2	N/A	29.1	12.8	N/A
		Option 6	48.2	N/A	29.1	51.8	N/A
	Medium 1	Option 1	2.0	N/A	30.4	24.2	N/A
		Options 2-4,7	12.8	N/A	150.3	24.2	N/A
		Option 5A	12.8	N/A	150.3	24.0	N/A
		Option 6	12.8	N/A	150.3	24.2	N/A
Swine - Grow-Finish Large CAFOs							
	Large 2	Option 1	2,142.5	3,250.0	2,199.4	N/A	N/A
		Options 2-4,7	9,170.9	94,549.9	14,414.4	N/A	N/A
		Option 5	4,643.4	48,935.6	5,021.8	N/A	N/A
		Option 6	9,170.9	94,549.9	11,568.8	N/A	N/A
	Large 1	Option 1	175.8	588.0	823.4	N/A	N/A
		Options 2-4,7	1,056.4	26,628.9	7,911.0	N/A	N/A
		Option 5	367.7	14,980.1	2,823.0	N/A	N/A
		Option 6	1,056.4	26,628.9	7,911.0	N/A	N/A

Table 4.1-6 (Continued)

Animal Type	Size Class	Regulatory Option	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Swine - Grow-Finish Medium CAFOs							
	Medium 3	Option 1	N/A	15.7	46.4	N/A	N/A
		Options 2-4,7	N/A	833.9	489.0	N/A	N/A
		Option 5	N/A	521.2	195.2	N/A	N/A
		Option 6	N/A	833.9	489.0	N/A	N/A
	Medium 2	Option 1	N/A	5.5	35.2	N/A	N/A
		Options 2-4,7	N/A	367.1	436.8	N/A	N/A
		Option 5	N/A	250.4	204.5	N/A	N/A
		Option 6	N/A	367.1	436.8	N/A	N/A
	Medium 1	Option 1	N/A	6.8	43.6	N/A	N/A
		Options 2-4,7	N/A	453.9	540.9	N/A	N/A
		Option 5	N/A	309.3	253.2	N/A	N/A
		Option 6	N/A	453.9	540.9	N/A	N/A
Swine - Farrow-to-Finish Large CAFOs							
	Large 2	Option 1	840.5	3,397.1	6,853.4	N/A	N/A
		Options 2-4,7	4,163.8	133,874.5	54,691.0	N/A	N/A
		Option 5	1,798.2	80,021.0	22,793.3	N/A	N/A
		Option 6	4,163.8	133,874.5	43,624.5	N/A	N/A
	Large 1	Option 1	175.8	588.0	823.4	N/A	N/A
		Options 2-4,7	1,249.0	11,438.5	12,716.9	N/A	N/A
		Option 5	366.6	6,197.4	4,075.5	N/A	N/A
		Option 6	1,249.0	11,438.5	12,716.9	N/A	N/A
Swine - Farrow-to-Finish Medium CAFOs							
	Medium 3	Option 1	N/A	6.9	52.3	N/A	N/A
		Options 2-4,7	N/A	455.4	694.2	N/A	N/A
		Option 5	N/A	246.6	233.6	N/A	N/A
		Option 6	N/A	455.4	694.2	N/A	N/A
	Medium 2	Option 1	N/A	5.5	54.5	N/A	N/A
		Options 2-4,7	N/A	404.7	788.5	N/A	N/A
		Option 5	N/A	230.0	288.0	N/A	N/A
		Option 6	N/A	404.7	788.5	N/A	N/A
	Medium 1	Option 1	N/A	6.0	59.4	N/A	N/A
		Options 2-4,7	N/A	439.9	860.0	N/A	N/A
		Option 5	N/A	249.9	314.1	N/A	N/A
		Option 6	N/A	439.9	860.0	N/A	N/A

Table 4.1-6 (Continued)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Broilers Large CAFOs							
	Large 2	Option 1	N/A	1,723.3	N/A	N/A	4,574.9
		Options 2-4,7	N/A	16,512.0	N/A	N/A	13,328.6
		Option 5	N/A	16,512.0	N/A	N/A	13,328.6
		Option 6	N/A	16,512.0	N/A	N/A	13,328.6
	Large 1	Option 1	N/A	987.4	N/A	N/A	2,177.1
		Options 2-4,7	N/A	10,572.9	N/A	N/A	6,865.8
		Option 5	N/A	10,572.9	N/A	N/A	6,865.8
		Option 6	N/A	10,572.9	N/A	N/A	6,865.8
Broilers Medium CAFOs							
	Medium 3	Option 1	N/A	107.5	N/A	N/A	235.2
		Options 2-4,7	N/A	1,345.8	N/A	N/A	829.0
		Option 5	N/A	1,345.8	N/A	N/A	829.0
		Option 6	N/A	1,345.8	N/A	N/A	829.0
	Medium 2	Option 1	N/A	78.4	N/A	N/A	153.9
		Options 2-4,7	N/A	981.2	N/A	N/A	542.5
		Option 5	N/A	981.2	N/A	N/A	542.5
		Option 6	N/A	981.2	N/A	N/A	542.5
	Medium 1	Option 1	N/A	41.9	N/A	N/A	72.7
		Options 2-4,7	N/A	571.9	N/A	N/A	273.7
		Option 5	N/A	571.9	N/A	N/A	273.7
		Option 6	N/A	571.9	N/A	N/A	273.7
Layers - Dry Large CAFOs							
	Large 2	Option 1	N/A	N/A	2,480.8	N/A	651.6
		Options 2-4,7	N/A	N/A	6,692.5	N/A	2,436.0
		Option 5	N/A	N/A	6,692.5	N/A	2,436.0
		Option 6	N/A	N/A	6,692.5	N/A	2,436.0
	Large 1	Option 1	N/A	N/A	3,448.2	N/A	1,399.0
		Options 2-4,7	N/A	N/A	9,170.4	N/A	4,954.1
		Option 5	N/A	N/A	9,170.4	N/A	4,954.1
		Option 6	N/A	N/A	9,170.4	N/A	4,954.1
Layers - Dry Medium CAFOs							
	Medium 3	Option 1	N/A	N/A	2.1	N/A	1.1
		Options 2-4,7	N/A	N/A	5.5	N/A	4.0
		Option 5	N/A	N/A	5.5	N/A	4.0
		Option 6	N/A	N/A	5.5	N/A	4.0

Table 4.1-6 (Continued)

Animal Type	Size Class	Regulatory Option	Central	Mid-Atlantic	Midwest	Pacific	South
Layers - Dry Medium CAFOs (cont.)							
	Medium 2	Option 1	N/A	N/A	7.2	N/A	4.3
		Options 2-4,7	N/A	N/A	19.2	N/A	15.4
		Option 5	N/A	N/A	19.2	N/A	15.4
		Option 6	N/A	N/A	19.2	N/A	15.4
	Medium 1	Option 1	N/A	N/A	10.0	N/A	8.0
		Options 2-4,7	N/A	N/A	22.7	N/A	23.6
		Option 5	N/A	N/A	22.7	N/A	23.6
		Option 6	N/A	N/A	22.7	N/A	23.6
Layers - Wet Large CAFOs							
	Large 1	Option 1	N/A	N/A	N/A	N/A	3,303.5
		Option 2	N/A	N/A	N/A	N/A	11,050.4
		Options 2-4,7	N/A	N/A	N/A	N/A	4,490.5
		Option 6	N/A	N/A	N/A	N/A	11,050.4
Layers - Wet Medium CAFOs							
	Medium 3	Option 1	N/A	N/A	N/A	N/A	9.8
		Options 2-4,7	N/A	N/A	N/A	N/A	29.3
		Option 5	N/A	N/A	N/A	N/A	10.7
		Option 6	N/A	N/A	N/A	N/A	29.3
Turkey Large CAFOs							
	Large 1	Option 1	N/A	853.4	1,451.1	N/A	N/A
		Options 2-4,7	N/A	13,025.4	4,483.9	N/A	N/A
		Option 5	N/A	13,025.4	4,483.9	N/A	N/A
		Option 6	N/A	13,025.4	4,483.9	N/A	N/A
Turkey Medium CAFOs							
	Medium 3	Option 1	N/A	7.9	5.3	N/A	N/A
		Options 2-4,7	N/A	99.1	14.9	N/A	N/A
		Option 5	N/A	99.1	14.9	N/A	N/A
		Option 6	N/A	99.1	14.9	N/A	N/A
	Medium 2	Option 1	N/A	9.6	6.2	N/A	N/A
		Options 2-4,7	N/A	121.3	17.6	N/A	N/A
		Option 5	N/A	121.3	17.6	N/A	N/A
		Option 6	N/A	121.3	17.6	N/A	N/A
	Medium 1	Option 1	N/A	10.5	6.7	N/A	N/A
		Options 2-4,7	N/A	132.4	19.0	N/A	N/A
		Option 5	N/A	132.4	19.0	N/A	N/A
		Option 6	N/A	132.4	19.0	N/A	N/A

N/A - Not Applicable.

waste must be hauled off site compared to Option 1. Dairy and swine emissions are lower when anaerobic digesters are used in Option 6. Composting (Option 5A for beef and dairy operations) has a limited impact on the emissions from transporting waste off site.

4.2 On-Site Composting Activities

Farm equipment used for on-site composting activities also affects the generation of air emissions. Option 5A for beef and dairy is based on all operations composting their waste; therefore, criteria air emissions from on-site composting of manure are shown only for beef and dairy Option 5A. Appendix F describes in detail the data and methodology used to calculate emissions for farm equipment used for on-site composting activities. Composting waste also reduces transportation air emissions if the volume or weight of material composted is reduced. Reductions in transportation emissions associated with the reduced material volume/weight are reflected in the transportation emissions described in Section 4.1.

4.2.1 Emissions Methodology

Criteria air emission estimates from composting are determined using the following assumptions (NRAES, 1992):

- Unit weight of manure is 62 lb/cf;
- All operations use windrow composting;
- Windrow height is 4.2 ft;
- Windrow width is 10 ft;
- Windrows are turned using a tractor attachment;
- Tractors that are used to turn manure travel at 1 mph;
- Tractors that are used to turn manure have 100 brake-horsepower (bhp) engines;
- Tractors turn the manure once a week (52 turns/year);

- A maximum of two months of waste is collected in the compost pile; and
- The compost windrow is turned using a rotary drum turner (the turner is a power take-off model that is propelled by a tractor).

4.2.2 Calculation of Emissions and Results

The amount of waste composted is based on the amount of excreted semi-solid waste. For this analysis, it is assumed that a maximum of two months of waste is collected on the compost pile. The annual amount of composted waste (including bedding) is divided by six to determine the weight composted in a two-month period, as shown in Equation 4-6. The cost model computes the annual amount of composted waste (U.S. EPA, 2002a).

$$\text{Maximum Composted Waste (lb)} = \frac{\text{Annual Composted Waste (lb)}}{6} \qquad [4\text{-}6]$$

The compost volume is calculated using the unit weight of composted waste, as shown in Equation 4-7.

$$\text{Maximum Composted Volume (cf)} = \frac{\text{Maximum Composted Waste (lb)}}{\text{Unit Weight (lb/cf)}} \qquad [4\text{-}7]$$

The cross-sectional area of the windrow is calculated using Equation 4-8. The windrow height and width are provided above.

$$\text{Windrow Cross-Sectional Area (sf)} = (2/3) \times \text{Windrow Height (ft)} \times \text{Windrow Width (ft)} \qquad [4\text{-}8]$$

Using the cross-sectional area, the length of the windrow is calculated as shown in Equation 4-9.

$$\text{Windrow Length (miles)} = \frac{\text{Maximum Composted Volume (cf)}}{\text{(Windrow Cross-Sectional Area (sf) x 5,280 ft/mile)}} \text{ x 52 turns/yr} \qquad [4\text{-}9]$$

The annual miles traveled during composting are calculated in the cost model (U.S. EPA, 2002a) and are presented in Table 4.2-1.

Table 4.2-1

Industry-Level Composting Miles Traveled Under Option 5A

Animal Type	Compost Miles
Beef	91,172
Heifer	1,867
Dairy	2,125

The annual criteria air emissions from composting operations are determined using the emissions factors shown in Table 4.1-1, the miles traveled along the length of the windrow, and Equation 4-10.

$$\text{Pollutant Emissions (tons/yr)} = \frac{\text{Windrow Length (miles)} \times \text{Emission Factor (gm/mile)}}{454\,\text{(lb/gm)} \times 2000\,\text{(ton/lb)}} \qquad [4\text{-}10]$$

Table 4.2-2 summarizes the results of criteria air pollutant emissions resulting from composting for each model farm in each region for Option 5A. The cost model assumes that composting takes place on site before transportation or land application. On-site emissions of criteria air pollutants due to composting activities increase under Option 5A for all beef feedlots, heifer operations, and dairies.

Table 4.2-2

Compost Pollutant Emissions for Model Farms Under Option 5A (lbs/yr)

Animal Type	Size Class	Criteria Pollutant	Region: Central	Region: Mid-Atlantic	Region: Midwest	Region: Pacific	Region: South
Beef Large CAFOs							
	Large 2	VOCs	59.49	1.10	106.85	6.36	N/A
		NOx	1,303.90	24.17	2,341.90	139.41	N/A
		CO	323.36	5.99	580.78	34.57	N/A
		PM	47.21	0.87	84.79	5.05	N/A
	Large 1	VOCs	13.47	0.21	24.24	1.51	N/A
		NOx	295.19	4.58	531.18	33.19	N/A
		CO	73.21	1.13	131.73	8.23	N/A
		PM	10.69	0.17	19.23	1.20	N/A
Beef Medium CAFOs							
	Medium 3	VOCs	0.17	0.01	0.46	0.02	0.00
		NOx	4.00	0.21	10.14	0.53	0.05
		CO	0.91	0.05	2.52	0.13	0.01
		PM	0.13	0.01	0.37	0.02	0.00
	Medium 2	VOCs	0.27	0.03	1.01	0.03	0.00
		NOx	5.83	0.66	22.16	0.58	0.08
		CO	1.45	0.16	5.50	0.14	0.02
		PM	0.21	0.02	0.80	0.02	0.00
	Medium 1	VOCs	0.33	0.04	1.24	0.03	0.00
		NOx	7.15	0.80	27.20	0.74	0.09
		CO	1.77	0.20	6.75	0.18	0.02
		PM	0.26	0.03	0.98	0.03	0.00
Dairy Large CAFOs							
	Large 1	VOCs	1.55	0.22	0.33	1.13	0.07
		NOx	34.02	4.85	7.28	24.68	1.51
		CO	8.44	1.20	1.81	6.12	0.38
		PM	1.23	0.18	0.26	0.89	0.05
Dairy Medium CAFOs							
	Medium 3	VOCs	0.04	0.04	0.04	0.02	0.01
		NOx	0.90	0.81	0.84	0.41	0.12
		CO	0.22	0.20	0.21	0.10	0.03
		PM	0.03	0.03	0.03	0.01	0.00

Table 4.2-2 (Continued)

Animal Type	Size Class	Criteria Pollutant	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Medium CAFOs (cont.)							
	Medium 2	VOCs	0.06	0.12	0.18	0.01	0.01
		NOx	1.22	2.69	3.93	0.28	0.20
		CO	0.30	0.67	0.97	0.07	0.05
		PM	0.04	0.10	0.14	0.01	0.01
	Medium 1	VOCs	0.09	0.20	0.29	0.02	0.02
		NOx	1.98	4.39	6.41	0.46	0.34
		CO	0.49	1.09	1.59	0.11	0.08
		PM	0.07	0.16	0.23	0.02	0.01
Heifer Large CAFOs							
	Large 1	VOCs	1.80	N/A	N/A	0.89	N/A
		NOx	40.17	N/A	N/A	19.41	N/A
		CO	9.96	N/A	N/A	4.81	N/A
		PM	1.45	N/A	N/A	0.70	N/A
Heifer Medium CAFOs							
	Medium 3	VOCs	0.13	N/A	0.10	0.03	N/A
		NOx	2.84	N/A	2.21	0.63	N/A
		CO	0.71	N/A	0.55	0.02	N/A
		PM	0.10	N/A	0.08	0.16	N/A
	Medium 2	VOCs	0.34	N/A	0.26	0.07	N/A
		NOx	7.55	N/A	5.79	1.63	N/A
		CO	1.87	N/A	1.44	0.06	N/A
		PM	0.27	N/A	0.21	0.40	N/A
	Medium 1	VOCs	0.08	N/A	1.28	0.03	N/A
		NOx	1.86	N/A	28.04	0.67	N/A
		CO	0.46	N/A	6.95	0.02	N/A
		PM	0.07	N/A	1.02	0.17	N/A

N/A - Not Applicable.

5.0 ENERGY IMPACTS

Certain regulatory options evaluated for animal feeding operations entail the use of different waste management systems and land application practices that may increase or decrease energy usage. Energy impacts related to land application are evaluated for animal feeding operations under baseline conditions and under the seven regulatory options considered by EPA. Energy impacts related to the use of anaerobic digesters are evaluated for all Large dairies and swine operations under Option 6.

5.1 Land Application

Applying animal waste to cropland requires energy in the form of electricity to operate the irrigation system. The regulatory options assume all beef feedlots, heifer operations, and dairies that have cropland apply their manure and wastewater using agronomic application rates; therefore, the manure application rates are calculated to be no greater than the nutrient uptake requirements for the crops grown in the fields on which the manure is applied. In many instances, facilities have to limit the amount of manure applied to the land, which may decrease on-site energy usage; however, an equivalent amount of energy is likely expended elsewhere to apply the manure and wastewater off site. EPA did not estimate energy impacts that occur off site.

The regulatory options may result in increased energy use for beef feedlots, heifer operations, dairies, and veal operations that need to capture runoff or other wastewater, divert it to a waste management system, and use the wastewater for irrigation. The regulatory options implementing a no-discharge policy would force these operations to collect and land apply their liquid waste using pivot irrigation systems or traveling guns, depending on the amount of acreage available for application. As a result of these application systems, the energy requirements of these operations would increase. Swine and poultry operations are not expected to have energy impacts from land application because it is assumed that all operations already land apply their waste.

5.1.1 Data Inputs

The estimation of the energy use associated with land application activities uses the following data inputs:

- Required horsepower per irrigated acre for center pivots and traveling guns; and
- Required flow rate per irrigated acre for traveling guns.

Table 5.1-1 presents the horsepower required to irrigate a specific number of acres using a center pivot system. These data were obtained from the *Zimmatic System Configuration Economic Comparison Guide* (Zimmatic, 2000) and are used in this analysis to establish a relationship between the number of acres irrigated and the electrical and diesel pump energy required.

Table 5.1-1

Required Horsepower for Center Pivots

Irrigated Acres	Required Horsepower
61	41
122	78
488	164

Source: Zimmatic, 2000.

Table 5.1-2 presents flow rates, in gallons per minute (gpm), required to irrigate a specific number of acres using a traveling gun system. These data were obtained from the *Kifco "B" Series Performance Guide* (Kifco, 2001). To use this information to relate irrigated acreage to horsepower requirements for traveling gun systems, it is necessary to know the horsepower required to achieve a given flow rate.   Data relating horsepower and flow rates for traveling guns were obtained from *Caprari Pumps Performance Data (*Caprari, 2002) and are presented in Table 5.1-3.

Table 5.1-2

Required Flow Rate for Traveling Guns

Irrigated Acres	Required Flow Rate (GPM)
66	17
87	23
110	29
126	33
143	37

Source: Kifco, 2001.

Table 5.1-3

Required Horsepower for Traveling Guns

Flow Rate (GPM)	Required Horsepower
50	13
60	14
70	15
80	16
90	17
100	17
150	21

Source: Caprari, 2002.

5.1.2 Energy Usage Methodology

To calculate the energy required for land application at a model farm, it is necessary to know the number of acres available for land application and the horsepower required to irrigate those acres.

In estimating the land required for irrigation, only the liquid portion of the manure is used. As described in the cost methodology report (U.S. EPA, 2002a), the following assumptions are made:

- All Large beef, heifer, and dairy CAFOs currently have sufficient land application/irrigation practices in place;

- Fifty percent of Medium beef and heifer CAFOs have land application/irrigation practices in place; and

- Ninety percent of Medium dairy CAFOs have land application/irrigation practices in place.

Acres available for liquid land application for farms classified as Category 1 and Category 2 are presented in the cost model methodology report (U.S. EPA, 2002a) and are used for the NWQI analysis for each model farm.

The amount of horsepower required for liquid land application at a model farm is based on the number of acres available for land application as calculated by the cost model. Equation 5-1 is used to calculate the horsepower required to irrigate the acres available for application at a model farm using a center pivot irrigation system, based on the data provided in Table 5.1-1:

$$\text{Required Horsepower (HP)} = (0.2695 \times \text{Irrigated Acres}) + 34.047 \qquad [5\text{-}1]$$

For liquid land application with a traveling gun irrigation system, the flow rate needed to irrigate the available acres is calculated using Equation 5-2, based on the data provided in Table 5.1-2.

$$\text{Required Flow Rate (GPM)} = (3.8465 \times \text{Irrigated Acres}) - 0.5332 \qquad [5\text{-}2]$$

The required horsepower is calculated using Equation 5-3, based on the data provided in Table 5.1-3.

$$\text{Required Horsepower (HP)} = (0.0783 \times \text{Flow Rate}) + 9.4348 \qquad [5\text{-}3]$$

Appendix G provides the derivation of these three equations.

Energy use from land application activities is approximated based on the assumption that facilities with more than 30 acres available for liquid land application use center pivot irrigation and facilities with less than 30 acres available use traveling gun irrigation. In addition, it is assumed that irrigation systems are operated 1,000 hours per year.

The energy use from liquid land application at a model farm is then calculated from the required horsepower using Equation 5-4.

$$\text{Energy Use per Model Farm (kW-hr/yr)} = \text{Required Horsepower} \times 1{,}000 \text{ hrs/yr} \times 0.7457 \text{ kW-hr/HP-hr} \times \text{Frequency Factor} \quad [5\text{-}4]$$

where:

Required Horsepower	=	The horsepower required to irrigate the acres available for land application at a model farm calculated in Equations 5-1 and 5-3
1,000 hrs/yr	=	The number of hours an irrigated system is operated per year
0.7457 kW-hr/HP-hr	=	The conversion factor from horsepower per hour to kilowatts per hour
Frequency Factor	=	Percentage of operations that do not currently apply liquid manure or runoff for irrigation.

5.1.3 Industry-Level Results

Table 5.1-4 presents the incremental electricity usage from baseline after implementation of the regulatory options at the industry level for center pivot and traveling gun irrigation systems. The change from the baseline scenario to each option scenario is directly related to the frequency factor of center pivot or traveling gun irrigation. In other words, if all of the facilities in a particular size group currently have a center pivot or traveling gun in place, the incremental change in electricity usage is zero. There is no change between baseline and Option 1 for Large CAFOs because no additional liquid application is expected; however, Medium CAFOs increase electrical use between baseline and Option 1 because some operations are expected to apply runoff that is not collected under baseline. The change in electricity usage is

Table 5.1-4

Incremental Industry-Level Electrical Usage for Center Pivot or Traveling Gun Irrigation by Regulatory Option (MW-hr/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef Large CAFOs							
	Large 2	Option 1	0	0	0	0	N/A
		Options 2-4, 7	5,153	226	12,230	1,945	N/A
		Option 5A	5,133	269	12,230	1,945	N/A
		Option 6	5,153	226	12,230	1,945	N/A
	Large 1	Option 1	0	0	0	0	N/A
		Options 2-4, 7	5,428	76	9,516	826	N/A
		Option 5A	5,428	76	9,516	826	N/A
		Option 6	5,428	76	9,516	826	N/A
Beef Medium CAFOs							
	Medium 3	Option 1	26.9	6.3	85.3	5.5	1.8
		Options 2-4, 7	38.7	7.9	259.1	22.2	1.9
		Option 5A	38.7	7.9	259.1	22.2	1.9
		Option 6	38.7	7.9	259.1	22.2	1.9
	Medium 2	Option 1	37.1	7.6	160.3	5.0	0.9
		Options 2-4, 7	48.2	20.4	227.8	20.2	2.2
		Option 5A	48.2	20.5	227.8	20.2	2.2
		Option 6	48.2	20.4	227.8	20.2	2.2
	Medium 1	Option 1	63.7	11.7	274.6	8.6	1.4
		Options 2-4, 7	77.6	33.7	357.4	35.2	1.6
		Option 5A	77.6	33.8	357.4	35.2	1.6
		Option 6	77.6	33.7	357.4	35.2	1.6
Dairy Large CAFOs							
	Large 1	Option 1	0	0	0	0	0
		Options 2-4, 7	3,070	1,126	964	9,513	243
		Option 5A	3,070	1,126	964	9,513	243
		Option 6	3,070	1,126	964	9,513	243

Table 5.1-4 (Continued)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Dairy Medium CAFOs							
	Medium 3	Option 1	9	28	15	11	6
		Options 2-4, 7	23	382	52	46	10
		Option 5A	23	387	52	46	10
		Option 6	23	382	52	46	10
	Medium 2	Option 1	17	119	92	10	14
		Options 2-4, 7	38	1,640	290	35	20
		Option 5A	38	1,658	290	35	20
		Option 6	38	1,640	290	35	20
	Medium 1	Option 1	45	299	242	27	36
		Options 2-4, 7	87	875	613	72	46
		Option 5A	87	909	613	72	46
		Option 6	87	875	613	72	46
Heifer Large CAFOs							
	Large 1	Option 1	0	N/A	N/A	0	N/A
		Options 2-4, 7	1,726	N/A	N/A	879	N/A
		Option 5A	1,726	N/A	N/A	879	N/A
		Option 6	1,726	N/A	N/A	879	N/A
Heifer Medium CAFOs							
	Medium 3	Option 1	38	N/A	39	14	N/A
		Options 2-4, 7	56	N/A	118	56	N/A
		Option 5A	56	N/A	118	56	N/A
		Option 6	56	N/A	118	56	N/A
	Medium 2	Option 1	88	N/A	87	30	N/A
		Options 2-4, 7	116	N/A	263	121	N/A
		Option 5A	116	N/A	263	121	N/A
		Option 6	116	N/A	263	121	N/A
	Medium 1	Option 1	32	N/A	598	17	N/A
		Options 2-4, 7	39	N/A	829	71	N/A
		Option 5A	39	N/A	829	71	N/A
		Option 6	39	N/A	829	71	N/A

greatest under Options 2 through 7, because some facilities apply manure waste using lower phosphorus-basis application rates; therefore, they apply their liquid manure over more acres.

5.2 Transportation

Transporting manure off site and composting manure on site requires using equipment such as trucks and tractors. The fuel consumption resulting from using these vehicles contributes to the energy impacts associated with land application activities.

5.2.1 Data Inputs

The estimation of fuel consumption by transportation vehicles uses the following data inputs:

- Number of miles traveled per year; and
- Vehicle fuel efficiency.

The cost model calculates the annual number of miles traveled to transport manure off site and perform composting activities on site for each model farm (U.S. EPA, 2002a), presented in Tables 4.1-2 and 4.2-1 of this report. The number of miles traveled depends on whether the model farm is a Category 2 or Category 3 facility, whether the facility purchases trucks or uses a contract hauler, the amount of solid waste and liquid waste transported, and whether nitrogen-based or phosphorous-based application is used. As described in Section 4.0, it is assumed that compost windrows are turned once a week by a tractor for a total of 52 turns per year (NRAES, 1992). This analysis also assumed that the farm vehicles used to transport manure and turn compost piles have an average fuel efficiency of six miles per gallon (mpg) (U.S. EPA, 2002c).

5.2.2 Energy Usage Methodology

The fuel consumption at a model farm resulting from transporting waste off site and composting of manure on site is calculated as follows:

$$\text{Fuel Consumption (gal/yr)} = \text{Miles Traveled (miles/yr)} \times 6 \text{ mpg} \qquad [5\text{-}5]$$

where:

Miles Traveled (miles/yr)	=	The number of miles traveled per year to transport manure off site and to perform composting activities, calculated by the cost model
6 mpg	=	Average fuel efficiency of vehicles used to transport manure (miles per gallon).

5.2.3 Industry-Level Results

Table 5.2-1 presents the industry-level incremental fuel consumption from baseline after implementation of the regulatory options for each type of operation.

5.3 Anaerobic Digesters with Methane Recovery

Option 6 includes the use of anaerobic digesters with energy recovery to manage animal waste for Large dairies and swine operations. Digesters require a continuous input of energy to operate the holding tank mixer and an engine to convert captured methane into energy.

5.3.1 Data Inputs

The energy required to continuously operate these devices and the amount of energy generated by the system have been determined from the *FarmWare* model, which is used in the cost model. Appendix H provides detailed data inputs and *FarmWare* model outputs used to calculate the energy impacts from anaerobic digester methane recovery.

Table 5.2-1

Industry-Level Fuel Usage for On-Site and Off-Site Transportation and Composting Activities by Regulatory Option

Animal Type	Size Category	Regulatory Option	Miles Traveled	Gallons of Fuel Used
Beef Large CAFOs				
	Large 2	Option 1	655,886	109,314
		Options 2-4, 7	11,831,760	1,971,960
		Option 5A	11,901,983	1,983,664
		Option 6	11,831,760	1,971,960
	Large 1	Option 1	412,528	109,314
		Options 2-4, 7	1,851,758	308,626
		Option 5A	1,870,820	311,803
		Option 6	1,870,820	311,803
Beef Medium CAFOs				
	Medium 3	Option 1	700	117
		Options 2-4, 7	6,125	1,021
		Option 5A	6,405	1,068
		Option 6	6,125	1,021
	Medium 2	Option 1	1,258	210
		Options 2-4, 7	8,107	1,351
		Option 5A	8,669	1,445
		Option 6	8,107	1,351
	Medium 1	Option 1	2,484	414
		Options 2-4, 7	10,702	1,784
		Option 5A	11,392	1,899
		Option 6	10,702	1,784
Dairy Large CAFOs				
	Large 1	Option 1	28,093,784	4,682,297
		Options 2-4, 7	60,186,466	10,031,078
		Option 5A	58,832,941	9,805,490
		Option 6	60,186,466	10,031,078

Table 5.2-1 (Continued)

Animal Type	Size Category	Regulatory Option	Miles Traveled	Gallons of Fuel Used
Dairy Medium CAFOs				
	Medium 3	Option 1	51,725	8,621
		Options 2-4, 7	340,149	56,692
		Option 5A	340,331	56,722
		Option 6	340,149	56,692
	Medium 2	Option 1	536,177	89,363
		Options 2-4, 7	1,361,313	226,886
		Option 5A	1,206,920	201,153
		Option 6	1,361,313	226,886
	Medium 1	Option 1	34,681	5,780
		Options 2-4, 7	1,290,654	215,109
		Option 5A	1,290,915	215,153
		Option 6	1,290,654	215,109
Heifer Medium CAFOs				
	Medium 3	Option 1	288	48
		Options 2-4, 7	5,054	842
		Option 5	5,071	845
		Option 6	5,054	842
	Medium 2	Option 1	1,663	277
		Options 2-4, 7	8,908	1,485
		Option 5	9,195	1,533
		Option 6	8,908	1,485
	Medium 1	Option 1	3,281	547
		Options 2-4, 7	13,109	2,185
		Option 5	13,696	2,283
		Option 6	13,109	2,185
Swine - Farrow-to-Finish Large CAFOs				
	Large 2	Option 1	643,084	107,181
		Options 2-4, 7	11,174,855	1,862,476
		Option 5	6,065,656	1,010,943
		Option 6	10,533,198	1,755,533

Table 5.2-1 (Continued)

Animal Type	Size Category	Regulatory Option	Miles Traveled	Gallons of Fuel Used
Swine - Farrow-to-Finish Large CAFOs (cont.)				
	Large 1	Option 1	89,734	14,956
		Options 2-4, 7	1,473,004	245,501
		Option 5	616,901	102,817
		Option 6	1,473,004	245,501
Swine - Farrow-to-Finish Medium CAFOs				
	Medium 3	Option 1	3,435	572
		Options 2-4, 7	66,661	11,110
		Option 5	27,844	4,641
		Option 6	66,661	11,110
	Medium 2	Option 1	3,478	580
		Options 2-4, 7	69,183	11,531
		Option 5	30,034	5,006
		Option 6	69,183	11,531
	Medium 1	Option 1	3,792	632
		Options 2-4, 7	75,370	12,562
		Option 5	32,699	5,450
		Option 6	75,370	12,562
Swine - Grow-Finish Large CAFOs				
	Large 2	Option 1	440,194	73,366
		Options 2-4, 7	6,849,729	1,141,622
		Option 5	3,397,800	566,300
		Option 6	6,684,737	1,114,123
	Large 1	Option 1	92,026	15,338
		Options 2-4, 7	2,063,948	343,991
		Option 5	1,053,580	175,597
		Option 6	2,063,948	343,991
Swine - Grow-Finish Medium CAFOs				
	Medium 3	Option 1	3,603	601
		Options 2-4, 7	76,704	12,784
		Option 5	41,543	6,924
		Option 6	76,704	12,784

Table 5.2-1 (Continued)

Animal Type	Size Category	Regulatory Option	Miles Traveled	Gallons of Fuel Used
Swine - Grow-Finish Medium CAFOs (cont.)				
	Medium 2	Option 1	2,363	394
		Options 2-4, 7	46,616	7,769
		Option 5	26,373	4,396
		Option 6	46,616	7,769
	Medium 1	Option 1	2,925	487
		Options 2-4, 7	57,681	9,613
		Option 5	32,616	5,436
		Option 6	57,681	9,613
Broiler - Large CAFOs				
	Large 2	Option 1	487,123	81,187
		Options 2-4, 7	2,307,939	384,656
		Option 5	2,307,939	384,656
		Option 6	2,307,939	384,656
	Large 1	Option 1	244,752	40,792
		Options 2-4, 7	1,348,753	224,792
		Option 5	1,348,753	224,792
		Option 6	1,348,753	224,792
Broiler - Medium CAFOs				
	Medium 3	Option 1	26,504	4,417
		Options 2-4, 7	168,207	28,035
		Option 5	168,207	28,035
		Option 6	168,207	28,035
	Medium 2	Option 1	17,965	2,994
		Options 2-4, 7	117,847	19,641
		Option 5	117,847	19,641
		Option 6	117,847	19,641
	Medium 1	Option 1	8,863	1,477
		Options 2-4, 7	65,403	10,901
		Option 5	65,403	10,901
		Option 6	65,403	10,901

Table 5.2-1 (Continued)

Animal Type	Size Category	Regulatory Option	Miles Traveled	Gallons of Fuel Used
Layer - Dry Large CAFOs				
	Large 2	Option 1	242,268	40,378
		Options 2-4, 7	706,019	117,670
		Option 5	706,019	117,670
		Option 6	706,019	117,670
	Large 1	Option 1	374,893	62,482
		Options 2-4, 7	1,092,423	182,070
		Option 5	1,092,423	182,070
		Option 6	1,092,423	182,070
Layer- Dry Medium CAFOs				
	Medium 3	Option 1	246	41
		Options 2-4, 7	730	122
		Option 5	730	122
		Option 6	730	122
	Medium 2	Option 1	894	149
		Options 2-4, 7	2,672	445
		Option 5	2,672	445
		Option 6	2,672	445
	Medium 1	Option 1	1,388	231
		Options 2-4, 7	3,583	597
		Option 5	3,583	597
		Option 6	3,583	597
Layer - Wet Large CAFOs				
	Large 1	Option 1	191,544	31,924
		Options 2-4, 7	640,724	106,787
		Option 5	260,370	43,395
		Option 6	640,724	106,787
Layer- Wet Medium CAFOs				
	Medium 3	Option 1	567	95
		Options 2-4, 7	1,699	283
		Option 5	623	104
		Option 6	1,699	283

Table 5.2-1 (Continued)

Animal Type	Size Category	Regulatory Option	Miles Traveled	Gallons of Fuel Used
Turkey Large CAFOs				
	Large 1	Option 1	178,235	29,706
		Options 2-4, 7	1,354,208	225,701
		Option 5	1,354,208	225,701
		Option 6	1,354,208	225,701
Turkey Medium CAFOs				
	Medium 3	Option 1	1,025	171
		Options 2-4, 7	8,819	1,470
		Option 5	8,819	1,470
		Option 6	8,819	1,470
	Medium 2	Option 1	1,223	204
		Options 2-4, 7	10,749	1,791
		Option 5	10,749	1,791
		Option 6	10,749	1,791
	Medium 1	Option 1	1,329	221
		Options 2-4, 7	11,710	1,952
		Option 5	11,710	1,952
		Option 6	11,710	1,952

5.3.2 Energy Usage Methodology

The cost model ran two different scenarios (i.e., before and after implementation of Option 6) using the *FarmWare* model to determine the energy impacts of two model farm dairies and ten swine model farm operations. Each dairy model represents a hose or flush Large dairy in Tulare, California. EPA believes that this model is representative of a Large dairy because the majority of Large dairies are in the Pacific region. Each swine model represents either a grow-finish or farrow-to-finish operation in each of the five regions, using either a pit, lagoon, or evaporative lagoon waste management system. The cost model assumes the model farms use the following waste management practices:

- Hose dairies use a solids separator followed by a complete mix digester;
- Flush dairies use a solids separator followed by a covered lagoon;
- All swine operations with pits (except Large 2 farrow-to-finish operations in the Mid-Atlantic region) use a pull plug system, followed by a new covered lagoon with a new second cell for effluent;
- Large 2 farrow-to-finish operations with pits in the Mid-Atlantic region use a scrape mix system with a storage tank, followed by a complete mix digester; and
- Lagoon and evaporative lagoon swine operations use a new covered lagoon, with the old cell used for effluent storage.

The baseline electricity is estimated by the *FarmWare* model as the total electricity required to run the dairy or swine operation. Appendix H provides an example model farm calculation for electricity use.

5.3.3 Model Farm Results

The estimated electrical usage for dairies at baseline and under Option 6 is presented in Table 5.3-1. Electricity use at dairy operations was only modeled for the Pacific region. Estimates of industry-level electricity use for all five regions are obtained by multiplying the model facility electrical use calculated for the Pacific region (kW-hr/yr) by the number of facilities in each region.

Table 5.3-1

Electrical Usage for Anaerobic Digestion at Dairies by Model Farm and Regulatory Option (kW-hr/yr)

Animal Type	Size Class	Regulatory Option	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Dairy - Hose	Large 1	Baseline	NC	NC	NC	1,396,344	NC
		Option 6	NC	NC	NC	139,284	NC
Dairy - Flush	Large 1	Baseline	NC	NC	NC	1,396,344	NC
		Option 6	NC	NC	NC	908,412	NC

NC - Not calculated. Model facility level estimates of electricity use for dairy operations are only calculated for the Pacific Region.

As shown in Table 5.3-1, it is estimated that there is a net decrease in electricity use of approximately 1,257,060 and 487,932 kilowatt hours annually for the dairy hose and dairy flush model farms, respectively, due to the energy savings of methane recovery using anaerobic digestion. This results in an energy savings of 1,024,574,418 kilowatt hours annually for all Large dairies.

Table 5.3-2 presents the estimated electrical usage at swine operations at baseline and under Option 6. Swine operations located in the Pacific and South regions were not modeled; therefore, electricity use was only calculated for the Central, Mid-Atlantic, and Midwest regions. The cost model estimates industry-level electricity use for these three regions by multiplying the model facility electrical use calculated for each region (kW-hr/yr) by the number of facilities in that region.

As shown in Table 5.3-2, there is a net decrease in annual electrical usage under Option 6 for Large swine grow-finish and farrow-to-finish operations in the Central, Mid-Atlantic, and Midwest regions. An annual energy savings of 1,042,211,364 and 1,175,353,728 kilowatt hours is expected for all Large 1 and Large 2 swine operations, respectively.

Table 5.3-2

Electrical Usage for Anaerobic Digestion at Swine Operations by Model Farm and Regulatory Option (kW-hr/yr)

Animal Type	Waste Management	Size Class	Regulatory Option	Region		
				Central	Mid-Atlantic	Midwest
Swine - Grow-Finish	Lagoon	Large 2	Baseline	3,398,004	1,059,960	1,189,608
			Option 6	1,817,700	520,344	652,620
		Large 1	Baseline	439,752	451,140	435,372
			Option 6	253,164	234,768	252,288
	Deep Pit	Large 2	Baseline	NA	1,059,960	1,189,608
			Option 6	NA	489,684	627,216
		Large 1	Baseline	NA	451,140	435,372
			Option 6	NA	222,504	243,528
Swine - Farrow-to-Finish	Lagoon	Large 2	Baseline	544,872	1,076,604	877,752
			Option 6	105,120	169,944	145,416
		Large 1	Baseline	1,815,948	581,664	649,992
			Option 6	253,164	57,816	119,136
	Deep Pit	Large 2	Baseline	NA	1,076,604	877,752
			Option 6	NA	107,748	109,500
		Large 1	Baseline	NA	581,664	649,992
			Option 6	NA	57,816	93,732

NA- Not applicable.

6.0 INDUSTRY-LEVEL NWQI ESTIMATES

This section summarizes the industry-level NWQI estimates for each of the regulatory options described in Section 1.2. To evaluate the impact of the final regulation on NWQI, the model farm emissions presented in Sections 2.0 through 5.0 can be extrapolated to the population of animal feeding operations covered by the rule, as shown in Equation 6-1. The model farm estimates in each region for feedlot operations presented in Section 2.0 are multiplied by the number of farms in each region, and the results for each region are summed. Next, the estimates by model farm are summed to arrive at the industry-level NWQI estimates by animal type.

$$\text{Emission}_{\text{animal}} = \sum_{\text{model farm}} \sum_{\text{region}} (\text{Model Farm Emission} \times \text{Number of Facilities}) \qquad [6\text{-}1]$$

Note that the model farm estimates in each region for land application activities, vehicle emissions, and energy impacts presented in Sections 3.0 through 5.0 are first multiplied by a model farm frequency factor based on the percentage of facilities classified as Category 1, 2, or 3. These results are then multiplied by the number of farms in each region. The results for each region are summed to arrive at the industry total NWQI estimates.

6.1 Summary of Air Emissions for Beef and Dairy Subcategories

Tables 6.2-1 and 6.2-2 present estimates for Large beef (includes heifer) and dairy CAFOs and Tables 6.2-7 and 6.2-8 present estimates for Medium beef (includes heifer) and dairy CAFOs. The tables are presented at the end of this section.

Option 1

Option 1 is expected to result in a change in precursor pollutant (i.e., ammonia and hydrogen sulfide) emissions from CAFOs. Total ammonia emissions from beef (includes heifer) and dairy CAFOs, including both the production area and land application activities, decrease under Option 1. Production area emissions decrease due to the added step of solids separation in waste management. Option 1 also requires agronomic application of manure, litter, and other process wastewater on site, which results in decreased application of manure nitrogen to cropland on site and decreased on-site land application ammonia emissions. However, off-site application of manure nitrogen increases, which also increases the off-site land application ammonia emissions. Hydrogen sulfide emissions from the production area decrease for dairies also because of the practice of solids separation, which allows for increased aerobic decomposition and the inhibition of hydrogen sulfide formation.

In addition, Option 1 is expected to result in a change in greenhouse gas emissions. For Large beef (includes heifer) and dairy CAFOs, methane emissions decrease due to the added step of solids separation in the waste management system. The separated solids are stockpiled rather than held in waste storage ponds or anaerobic lagoons. This drier method of manure handling reduces anaerobic conditions and the potential for volatile solids to convert to methane. This approach also results in greater conversion of nitrogen to nitrous oxide; thus, nitrous oxide emissions from dairies increase. For Medium beef (includes heifer) CAFOs, methane emissions increase due to increased liquid storage from baseline.

Due to the requirement under Option 1 to apply manure, litter, and other process wastewater at nitrogen-based agronomic rates, CAFOs with insufficient land on which to apply their waste at these rates will transport the excess manure off site. Due to this increase in transportation, emissions of criteria air pollutants increase from baseline for beef (includes heifer) and dairy CAFOs.

Options 2-4 and 7

Options 2-4 and 7 also result in changes to precursor and greenhouse gas emissions as discussed for Option 1. However, these options require manure, litter, and other process wastewater to be applied at agronomic rates for phosphorus for some operations. Therefore, criteria air emissions increase compared to baseline and Option 1 due to an increase in the amount of manure nutrients transported off site.

Option 5A

Option 5A requires the implementation of composting at beef (includes heifer) and dairy CAFOs. Under Option 5A, ammonia emissions increase for these operations. Ammonia volatilizes rapidly from drying manure, resulting in an increase in emissions as more manure is handled as a solid rather than a liquid or slurry. In addition, composting practices release more emissions than stockpiles because the windrows are turned regularly, exposing more manure to the air. Stockpiles tend to form outer crusts that reduce the potential for volatilization.

Under a composting option, production area methane emissions increase as a result of the addition of organic material to the waste prior to composting. This material decomposes and contributes to increased methane emissions compared to other options and baseline. Nitrous oxide emissions also increase for these operations, as aerobic storage enhanced by windrow turning promotes the release of this gas.

Option 5A also results in an increase in criteria air emissions. The practice of composting requires turning equipment, which consumes fuel and generates additional air emissions. However, this increase is not as large as the increase under Options 2-4, 6, and 7. The additional criteria pollutants emitted by composting equipment is partially offset by reductions in transportation emissions, resulting from a decrease in the weight and/or volume of the composted material.

Option 6

Under Option 6, emissions of pollutants do not differ from Option 2 for all beef (includes heifer) CAFOs, and for Medium dairy CAFOs. However, for Large dairy CAFOs, this option results in changes to greenhouse gas and criteria air emissions. Methane and nitrous oxide emissions from the production area of Large dairy CAFOs decrease substantially, due to the addition of an anaerobic digester with energy recovery. Generated methane is collected as biogas and converted to energy, and nitrous oxide is oxidized during the combustion process. Emissions of nitrogen oxides, carbon monoxide, and sulfur dioxide increase due to combustion of the biogas.

6.2 Summary of Air Emissions for Swine, Poultry, and Veal Operations

Tables 6.2-3 through 6.2-6 present estimates for Large veal, swine, and poultry CAFOs and Tables 6.2-9 through 6.2-12 present estimates for Medium veal, swine, and poultry CAFOs.

Option 1

Emissions of precursor pollutants and greenhouse gases do not change for veal, swine, and poultry operations under Option 1, as this option does not result in changes to the production area waste management procedures. However, criteria air pollution increases for swine and poultry operations due to the nitrogen-based application requirements and the associated increases in transportation of manure nutrients off site. Emissions for veal operations do not change from baseline because it is assumed that they have adequate cropland to apply all waste on site and consequently do not transport any manure.

Options 2-4 and 7

Under these options, emissions of precursor pollutants and greenhouse gases do not change from baseline for all veal, swine, and poultry operations, as waste handling practices are not expected to change.

As in Option 1, there is no increase in criteria air pollutant emissions for veal operations because they are not expected to transport manure off site. However, there is an increase in criteria air pollutant emissions for swine and poultry operations when compared to baseline and Option 1 because of the increased transport of waste necessitated by the phosphorus-based application requirement.

Option 5

Option 5 requires zero discharge, with no allowance for overflow. It is expected that operations will implement total confinement and covered storage, in addition to the requirements of Option 2, for all swine, poultry, and veal operations. Under this option, ammonia emissions decrease for veal, swine, and chicken operations. Usually, ammonia in the effluent from the covered lagoon is released upon exposure to air. Option 5, however, is based on covered storage at all times; thus, depending on the application methods (e.g., if the waste is incorporated into the soil), ammonia emissions could substantially decrease. The use of a covered lagoon lowers the production area ammonia emissions. It should be noted, however, that ammonia emissions increase from material applied to land both on site and off site. Ammonia emissions from turkey operations do not change compared to baseline. Emissions of hydrogen sulfide decrease for veal and swine and drop to zero for wet-layer operations due to the practice of covered storage.

Methane and nitrous oxide emissions from the production area decrease for all veal, chicken, and swine operations as a result of total confinement and covered storage. However, nitrous oxide emissions increase from material applied to land both on site and off site.

Veal operations emit a larger quantity of nitrogen oxides, carbon monoxide, and sulfur dioxide compared with baseline and all other options due to flaring. Wet layer and swine operations also emit additional criteria air pollutants compared to baseline because of this practice. However, compared to Options 2-4 and 7, these operations emit a smaller amount of VOCs, nitrogen oxides, particulate matter, and carbon monoxide but a larger amount of sulfur dioxide under Option 5. For turkey operations, criteria air emissions under Option 5 increase from baseline to the same level that results from Options 2-4, 6 and 7.

Option 6

Under Option 6, emissions of precursor pollutants do not differ from Option 2 for all veal and poultry CAFOs and for Medium swine CAFOs. However, for Large swine CAFOs, this option results in changes to greenhouse gas and criteria air emissions. Methane and nitrous oxide emissions from the production area of Large swine CAFOs decrease substantially, due to the addition of an anaerobic digester with energy recovery. Generated methane is collected as biogas and converted to energy, and nitrous oxide is oxidized during the combustion process. Emissions of nitrogen oxides, carbon monoxide, and sulfur dioxide increase due to combustion of the biogas.

6.3 Energy Impacts

The regulatory options evaluated for CAFOs are based on the use of certain waste management systems and land application practices that may impact electricity and fuel usage. Both energy usage indicators were estimated in relation to baseline, with electricity usage in units of megawatt-hours per year (MW-hr/yr) and fuel usage in gallons.

Increased electricity usage occurs at beef (includes heifer) and dairy CAFOs under all options. Surface runoff from the feedlot must be collected and stored before it can be land applied. These additional measures require an increase in electricity expenditures. Because veal, poultry, and swine are confined in houses, these operations do not experience elevated electricity demands, as there are no additional runoff controls expected. In addition, the land application of waste consumes electricity during the operation of the irrigation system. It is assumed that swine and poultry operations already land apply their waste and therefore do not experience additional electricity needs. However, some beef (includes heifer) operations and dairies do not currently collect and land apply their liquid waste, and a zero discharge policy would likely result in these operations collecting and land applying this waste using new irrigation systems. As a result, the energy requirements of these operations are expected to increase.

Under Option 1, all operations except veal operations experience an increase in fuel usage due to the requirement that manure be land applied according to agronomic rates for nitrogen. This requirement is expected to result in excess manure nutrients being transported to off-site land application sites. This fuel usage grows under Options 2-4, 6 and 7 because of the more stringent phosphorus-based requirement and the resultant increase in the amount of manure to be transported. Veal operations are assumed to apply all waste on site no matter the option and thus do not incur additional energy costs.

Under Option 5, swine and chicken operations use less fuel as a result of the total confinement and covered storage requirements. Fuel consumption at veal and turkey operations does not change from baseline under any option.

Under Option 5A, which requires composting at beef (includes heifer) and dairy CAFOs, fuel usage by transportation vehicles decreases due to a decrease in the weight and/or volume of the waste. Nevertheless, because of the fuel demands of the composting equipment, total fuel usage at beef and heifer operations increases compared to other options. Because all beef (includes heifer) waste is deposited on the drylot, a large amount of waste is available for composting. The additional fuel usage of composting equipment at these operations offsets the decrease from lower transportation fuel requirements. At dairies, however, much of the manure is in liquid and slurry form and less solid waste can be composted. Consequently, the energy demands of the composting equipment do not outweigh the energy saved from a reduction in transportation, and the overall fuel usage for dairies decreases under Option 5A.

Overall electricity use decreases at those operations that use anaerobic digesters under Option 6. Large swine and dairy CAFOs that digest their waste and recover and use the biogas to operate an engine generate excess energy, which can be sold or used to operate other machinery.

Table 6.2-1

NWQIs for Beef (Includes Heifers) - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	385,256	383,154	383,154	383,154	383,154		505,713	383,154	383,154
Hydrogen Sulfide (H_2S)	NC	NC	NC	NC	NC		NC	NC	NC
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.93	0.86	0.86	0.86	0.86		1.13	0.86	0.86
Nitrous Oxide (N_2O)	7.72	7.72	7.72	7.72	7.72		7.93	7.72	7.72
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	1.4	18.6	18.6	18.6		18.7	18.6	18.6
Nitrogen Oxides (NOx)	Baseline	29.3	387.5	387.5	387.5		389.8	387.5	387.5
Particulate Matter (PM)	Baseline	1.0	12.9	12.9	12.9		13.0	12.9	12.9
Carbon Monoxide (CO)	Baseline	7.6	103.8	103.8	103.8		104.4	103.8	103.8
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC		NC	NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	37,986	37,986	37,986		38,257	37,986	37,986
Fuel Usage (gallons/yr)	Baseline	178,069	2,280,586	2,280,586	2,280,586		2,295,467	2,280,586	2,280,586

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-2

NWQIs for Dairy - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	151,595	147,591	147,591	147,591	147,591		162,576	147,591	147,591
Hydrogen Sulfide (H_2S)	5,986	3,611	3,611	3,611	3,611		3,611	3,611	3,611
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	5.85	3.60	3.60	3.60	3.60		3.68	0.02	3.60
Nitrous Oxide (NOx)	1.46	1.95	1.95	1.95	1.95		2.72	0.56	1.95
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	42.4	90.8	90.8	90.8		88.7	90.8	90.8
Nitrogen Oxides (NOx)	Baseline	850.3	1820.1	1820.1	1820.1		1779.0	1841.3	1820.1
Particulate Matter (PM)	Baseline	26.5	56.8	56.8	56.8		55.5	56.8	56.8
Carbon Monoxide (CO)	Baseline	240.5	514.3	514.3	514.3		502.7	519.7	514.3
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC		NC	20.1	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	14,430	14,430	14,430		14,430	(1,009,331)	14,430
Fuel Usage (gallons/yr)	Baseline	4,682,297	10,031,078	10,031,078	10,031,078		9,805,490	10,031,078	10,031,078

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-3

NWQIs for Veal - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	149	149	149	149	149	104		149	149
Hydrogen Sulfide (H_2S)	10	10	10	10	10	2		10	10
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.001	0.001	0.001	0.001	0.001	0.000		0.001	0.001
Nitrous Oxide (N_2O)	0.0017	0.0017	0.0017	0.0017	0.0017	0.0021		0.0017	0.0017
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Nitrogen Oxides (NOx)	Baseline	Baseline	Baseline	Baseline	Baseline	0.41		Baseline	Baseline
Particulate Matter (PM)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Carbon Monoxide (CO)	Baseline	Baseline	Baseline	Baseline	Baseline	0.36		Baseline	Baseline
Sulfur Dioxide (SO_2)	Baseline	Baseline	Baseline	Baseline	Baseline	0.41		Baseline	Baseline
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-4

NWQIs for Swine - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	183,732	183,732	183,732	183,732	183,732	109,037		183,732	183,732
Hydrogen Sulfide (H_2S)	13,036	13,036	13,036	13,036	13,036	2,150		13,036	13,036
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	12.46	12.46	12.46	12.46	12.46	2.27		0	12.46
Nitrous Oxide (NOx)	0.29	0.29	0.29	0.29	0.29	0.52		0.20	0.29
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	1.9	32.8	32.8	32.8	16.9		31.5	32.8
Nitrogen Oxides (NOx)	Baseline	38.5	655.4	655.4	655.4	404.7		700.8	655.4
Particulate Matter (PM)	Baseline	1.2	20.4	20.4	20.4	10.5		19.6	20.4
Carbon Monoxide (CO)	Baseline	10.9	185.9	185.9	185.9	154.1		196.8	185.9
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	66.0		66.0	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		(2,217,565)	Baseline
Fuel Usage (gallons/yr)	Baseline	210,840	3,593,589	3,593,589	3,593,589	1,855,656		3,459,148	3,593,589

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-5

NWQIs for Chickens - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	205,038	205,038	205,038	205,038	205,038	200,755		205,038	205,038
Hydrogen Sulfide (H_2S)	1,146	1,146	1,146	1,146	1,146	0		1,146	1,146
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	1.19	1.19	1.19	1.19	1.19	0.27		1.19	1.19
Nitrous Oxide (N_2O)	2.30	2.30	2.30	2.30	2.30	2.40		2.30	2.30
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	1.9	7.5	7.5	7.5	6.9		7.5	7.5
Nitrogen Oxides (NOx)	Baseline	41.0	161.7	161.7	161.7	152.7		161.7	161.7
Particulate Matter (PM)	Baseline	1.5	5.8	5.8	5.8	5.4		5.8	5.8
Carbon Monoxide (CO)	Baseline	10.4	40.8	40.8	40.8	39.8		40.8	40.8
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	2.6		NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	256,763	1,015,976	1,015,976	1,015,976	952,584		1,015,976	1,015,976

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-6

NWQIs for Turkeys - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	35,599	35,599	35,599	35,599	35,599	35,599		35,599	35,599
Hydrogen Sulfide (H_2S)	NC	NC	NC	NC	NC	NC		NC	NC
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.09	0.09	0.09	0.09	0.09	0.09		0.09	0.09
Nitrous Oxide (N_2O)	1.05	1.05	1.05	1.05	1.05	1.05		1.05	1.05
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.2	1.6	1.6	1.6	1.6		1.6	1.6
Nitrogen Oxides (NOx)	Baseline	4.6	35.3	35.3	35.3	35.3		35.3	35.3
Particulate Matter (PM)	Baseline	0.2	1.3	1.3	1.3	1.3		1.3	1.3
Carbon Monoxide (CO)	Baseline	1.2	8.8	8.8	8.8	8.8		8.8	8.8
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	NC		NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	29,706	225,701	225,701	225,701	225,701		225,701	225,701

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-7

NWQIs for Beef (Includes Heifers) - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	3990	3964	3964	3964	3964		5386	3964	3964
Hydrogen Sulfide (H_2S)	NC	NC	NC	NC	NC		NC	NC	NC
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.012	0.013	0.013	0.013	0.013		0.016	0.013	0.013
Nitrous Oxide (N_2O)	0.08	0.08	0.08	0.08	0.08		0.10	0.08	0.08
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.012	0.067	0.067	0.067		0.070	0.067	0.067
Nitrogen Oxides (NOx)	Baseline	0.3	1.4	1.4	1.4		1.5	1.4	1.4
Particulate Matter (PM)	Baseline	0.009	0.049	0.049	0.049		0.051	0.049	0.049
Carbon Monoxide (CO)	Baseline	0.07	0.37	0.37	0.37		0.39	0.37	0.37
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC		NC	NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	1,640	2,821	2,821	2,821		2,822	2,821	2,821
Fuel Usage (gallons/yr)	Baseline	1,613	8,668	8,668	8,668		9,071	8,668	8,668

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-8

NWQIs for Dairy - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 5A**	**Option 6**	**Option 7**
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	39,837	39,185	39,185	39,185	39,185		48,337	39,185	39,185
Hydrogen Sulfide (H_2S)	1,068	598	598	598	598		598	598	598
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.97	0.64	0.64	0.64	0.64		0.67	0.64	0.64
Nitrous Oxide (N_2O)	0.585	0.589	0.589	0.589	0.589		0.818	0.589	0.589
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.9	4.3	4.3	4.3		4.0	4.3	4.3
Nitrogen Oxides (NOx)	Baseline	18.4	87.5	87.5	87.5		82.8	87.5	87.5
Particulate Matter (PM)	Baseline	0.6	2.8	2.8	2.8		2.7	2.8	2.8
Carbon Monoxide (CO)	Baseline	5.1	24.1	24.1	24.1		22.7	24.1	24.1
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC		NC	NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	970	4,228	4,228	4,228		1,667	4,228	4,228
Fuel Usage (gallons/yr)	Baseline	103,764	498,686	498,686	498,686		473,028	498,686	498,686

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-9

NWQIs for Veal - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	12	12	12	12	12	8		12	12
Hydrogen Sulfide (H_2S)	0.7	0.7	0.7	0.7	0.7	0.2		0.7	0.7
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000		0.0001	0.0001
Nitrous Oxide (N_2O)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002		0.0001	0.0001
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Nitrogen Oxides (NOx)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Particulate Matter (PM)	Baseline	Baseline	Baseline	Baseline	Baseline	NC		Baseline	Baseline
Carbon Monoxide (CO)	Baseline	Baseline	Baseline	Baseline	Baseline	0.04		Baseline	Baseline
Sulfur Dioxide (SO_2)	Baseline	Baseline	Baseline	Baseline	Baseline	0.04		Baseline	Baseline
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-10

NWQIs for Swine - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	10,596	10,596	10,596	10,596	10,596	7,090		10,596	10,596
Hydrogen Sulfide (H_2S)	616	616	616	616	616	183		616	616
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.68	0.68	0.68	0.68	0.68	0.19		0.68	0.68
Nitrous Oxide (N_2O)	0.02	0.02	0.02	0.02	0.02	0.03		0.02	0.02
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.0	0.6	0.6	0.6	0.3		0.6	0.6
Nitrogen Oxides (NOx)	Baseline	0.6	11.9	11.9	11.9	7.5		11.9	11.9
Particulate Matter (PM)	Baseline	0.0	0.4	0.4	0.4	0.2		0.4	0.4
Carbon Monoxide (CO)	Baseline	0.2	3.4	3.4	3.4	3.1		3.4	3.4
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	1.6		NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	3,266	65,369	65,369	65,369	31,852		65,369	65,369

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-11

NWQIs for Chickens - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	6,287	6,287	6,287	6,287	6,287	6,276		6,287	6,287
Hydrogen Sulfide (H_2S)	3.1	3.1	3.1	3.1	3.1	0.0		3.1	3.1
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.040	0.040	0.040	0.040	0.040	0.038		0.040	0.040
Nitrous Oxide (N_2O)	0.1427	0.1427	0.1427	0.1427	0.1427	0.1430		0.1427	0.1427
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.07	0.43	0.43	0.43	0.43		0.43	0.43
Nitrogen Oxides (NOx)	Baseline	1.47	9.40	9.40	9.40	9.47		9.40	9.40
Particulate Matter (PM)	Baseline	0.05	0.34	0.34	0.34	0.43		0.34	0.34
Carbon Monoxide (CO)	Baseline	0.37	2.33	2.33	2.33	2.32		2.33	2.33
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	0.11		NC	NC
Baseline + Energy Usage[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	9,404	60,024	60,024	60,024	59,844		60,024	60,024

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 6.2-12

NWQIs for Turkeys - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	603	603	603	603	603	603		603	603
Hydrogen Sulfide (H_2S)	NC	NC	NC	NC	NC	NC		NC	NC
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.002	0.002	0.002	0.002	0.002	0.002		0.002	0.002
Nitrous Oxide (N_2O)	0.018	0.018	0.018	0.018	0.018	0.018		0.018	0.018
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.00	0.04	0.04	0.04	0.04		0.04	0.04
Nitrogen Oxides (NOx)	Baseline	0.09	0.82	0.82	0.82	0.82		0.82	0.82
Particulate Matter (PM)	Baseline	0.00	0.03	0.03	0.03	0.03		0.03	0.03
Carbon Monoxide (CO)	Baseline	0.02	0.20	0.20	0.20	0.20		0.20	0.20
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	NC		NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	596	5,213	5,213	5,213	5,213		5,213	5,213

NC - Not calculated.

[a]Energy estimates reflect the incremental change in usage from baseline.

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Appendix A

Emission Factor Derivation and Detailed Calculations for Air Emissions from Animal Confinement and Manure Management Systems - Ammonia and Hydrogen Sulfide Emissions

INTRODUCTION

Appendix A presents the derivation of ammonia and hydrogen sulfide emission factors for drylots, confinement houses, and lagoons and ponds and example calculations for ammonia and hydrogen sulfide emissions from manure management systems. The emission calculations follow the methodology presented in Section 2.1 of this report.

A.1 Derivation of Emission Factors

The ammonia emission factors for drylots at cattle operations were based on data from North Carolina Cooperative Exention Service's (NCCES) "*Livestock Manure Production and Characterization in North Carolina*." The ammonia and hydrogen sulfide emission factors for confinement houses and lagoons and ponds were calculated based on the results of a literature review conducted by EPA's Office of Air Quality Planning and Standards (OAQPS). To calculate each emission factor, the applicable data points identified in the literature review were converted to lb NH_3/yr/head and then averaged. For several operations, no applicable data points were identified. For these operations, the emission factors were transferred from swine operations using the percent loss of nitrogen or sulfur. To calculate the percent loss of nitrogen or hydrogen sulfide, it was necessary to determine the amount of nitrogen or hydrogen sulfide entering either the confinement house or the lagoon or pond. This was done by tracing the flow of nitrogen or hydrogen sulfide through the different components of the waste management system. The applicable data points for each emission factor and the calculations used to estimate the emission factors are presented in the tables below.

A.1.1 Drylots

The ammonia emission factors for drylots at cattle operations (i.e., dairy, beef, and heifer) are based on the NCCES data for cattle presented in Table A-1.

Table A-1

Nitrogen Content of Fresh and Drylot Manure at Cattle Operations

Constituent	Fresh Manure[1]	Beef Unpaved Feedlot Manure[a]	Difference Between Fresh and Unpaved Manure	Percent of Nitrogen Lost
	(ton/day/head)			
Total Kjeldahl Nitrogen	0.290	0.159	0.131	45

[1]NCCES. 1994a. *Livestock Manure Production and Characterization in North Carolina*. North Carolina Cooperative Extension Service. North Carolina State University, January 1994. Tables 6 and 8A.

The difference in the nitrogen content of the fresh manure and drylot manure represents the amount of nitrogen lost from the drylot. Most of the nitrogen loss at the drylot occurs as ammonia emissions; however, some of the nitrogen excreted at the drylot is carried away in the runoff. Equation 2-2 in Section 2.1 of this report was used to calculate the net amount of nitrogen contributing to ammonia emissions at cattle drylots (i.e., the portion of the manure excreted at the drylot that is not removed with the drylot runoff). Then, Equation 2-3 was used to calculate the drylot ammonia emission factors.

A.1.2 Confinement Houses

Ammonia and hydrogen sulfide emission factors were calculated for several different types of confinement houses to account for variations in emissions from different operations and waste management systems.

A.1.2.1 Ammonia

Houses with Lagoon System and Flush Houses

The literature search performed by OAQPS yielded several applicable data points for swine houses with lagoon systems, but no applicable data points for either dairy or veal flush houses. Swine confinement houses with lagoon systems and dairy and veal flush houses have similar waste management practices; therefore, the ammonia emission factor for swine houses with lagoon systems was transferred to veal and dairy flush houses.

Swine

The ammonia emission factor for swine houses with lagoon systems is based on data identified from OAQPS's literature review. Table A-2 presents the data points and calculations used to estimate this emission factor.

Table A-2

Calculation of the Ammonia Emission Factor for Swine Houses with Lagoon Systems

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Hoeksma et al., 1993	3.0-5.0	g/animal/day	4	119 days/cycle, 2.8 cycles/yr, 1 lb/453.6 g	2.9
Hoeksma et al., 1993	2.0-5.0	g/animal/day	3.5	119 days/cycle, 2.8 cycles/yr, 1 lb/453.6 g	2.6
Oosthoek et al., 1998	3.1	kg/animal/yr	3.1	2.2046 lb/kg	6.8
AVERAGE					**4.1**

Dairy and Veal

The ammonia emission factors for flush barns at dairies and veal operations are based on the percent loss of nitrogen from swine confinement houses with lagoon systems. The percent loss of nitrogen represented by the swine house with lagoon system emission factor was calculated using Equation A-1.

$$\%\ \text{Loss of}\ N_{house} = \frac{\text{Ammonia Housing Emission Rate}_{swine} \times CF}{\text{Manure Nitrogen}_{excreted}} \times 100\% \qquad \text{(A-1)}$$

where:

% Loss of N_{house}	=	Percent of nitrogen excreted in swine confinement house lost as ammonia
Ammonia Housing Emission Rate_{swine}	=	Ammonia emission factor for the swine confinement house (lb/yr/head)
CF	=	Conversion factor (14 N/17 NH_3)
Manure $\text{Nitrogen}_{excreted}$	=	Nitrogen excreted at the confinement house (lb/yr/head).

It is estimated that 18.9 lb N/yr/head is excreted at the confinement houses of swine operations. As shown in Table A-1, the swine house with lagoon system emission factor is 4.1 lb NH_3/yr/head; therefore, using Equation A-1, the percentage of nitrogen lost from the house as ammonia is:

$$= \frac{4.1\ \text{lb}\ NH_3/\text{yr}/\text{head} \times \frac{14\ N}{17\ NH_3}}{18.9\ \text{lb N}/\text{yr}/\text{head}} \times 100\%$$

$$= 17.9\%$$

Equation A-2 was then used to convert the percent loss of nitrogen at swine confinement houses to an emission factor in lb NH_3/yr/head for dairy flush houses.

$$\text{Ammonia Housing Emission Rate}_{dairy} = \text{Manure Nitrogen}_{excreted} \times \%\ \text{Loss of N}_{house} \times \text{CF} \qquad \text{(A-2)}$$

where:

Ammonia Housing Emission Rate$_{dairy}$	=	Ammonia emission factor for the dairy flush house (lb/yr/head)
Manure Nitrogen$_{excreted}$	=	Nitrogen excreted at the dairy flush house (lb/yr/head)
% Loss of N$_{house}$	=	Percentage of nitrogen excreted in swine confinement house lost as ammonia calculated in Equation A-1
CF	=	Conversion factor (14 N / 17 NH_3).

It is estimated that 188 lb N/yr/head is excreted at a dairy flush house. As calculated using Equation A-1, 17.9 percent of the nitrogen excreted at a swine confinement house with a lagoon system is lost as ammonia; therefore, using Equation A-2, the ammonia emission factor for flush houses at a dairy operations is:

$$= 188 \text{ lb N / yr / head} \times 0.179 \times \frac{17\ NH_3}{14N}$$

$$= 40.9 \text{ lb } NH_3 \text{ /yr/head}$$

Veal operations have a nitrogen excretion rate of 28 lb N/yr/head; therefore, using Equation A-2, a loss of 4.6 lb N/yr/head (5.6 lb NH_3/yr/head) is expected.

Houses with Deep-Pit Systems

The ammonia emission factor for swine houses with deep-pit systems is based on data identified from the literature review. However, there were no applicable data points identified for veal houses with deep-pit systems; therefore, the ammonia emission factor for swine houses with deep-pit systems was transferred to veal houses with deep-pit systems.

Swine

The literature search identified seven applicable data points for swine houses with deep-pit systems. Table A-3 presents these data points and the calculations used to estimate the emission factor.

Veal

The ammonia emission factor for veal houses with deep-pit systems is based on the percent loss of nitrogen from swine houses with deep-pit systems. Swine operations have a nitrogen excretion rate of 18.9 lb N/yr/head. Using Equation A-1, a loss of 8.2 lb NH_3/yr/head

(6.8 lb N/yr/head) from the confinement house represents 35.7 percent of the nitrogen excreted per year. Using Equation A-2, and given that veal operations have a nitrogen excretion rate of 28 lb N/yr/head, a loss of 9.1 lb N/yr/head (11.1 lb NH_3/yr/head) is expected from veal houses with deep-pit systems.

Dairy Scrape Barns

The ammonia emission factor for scrape barns at dairy operations is based on data identified from the literature review. Table A-4 presents the data points and calculations used to estimate this emission factor.

Table A-3

Calculation of the Ammonia Emission Factor for Swine Houses with Deep-Pit Systems

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Battye et al., 1994	3.18	kg/fattening pig/yr	3.18	2.2046 lb/kg	7.0
Secrest, 1999	34.9-44.6	lb/day/2000 finishing hogs	39.75	119 days/cycle, 2.8 cycles/yr	6.6
Hoeksma et al., 1993	10.0-12.0	g NH3/animal/day	11.0	119 days/cycle, 2.8 cycles/yr, 1 lb/453.6 g	8.1
USDA, 2000	13	g/hd/day	13.0	119 days/cycle, 2.8 cycles/yr, 1 lb/453.6 g	9.5
Ni et al. 2000c	145	g NH_3/500 kg LW-day	145	1 lb/453.6 g, 0.4536 kg/lb, 135 lb/head, 119 days/cycle, 2.8 cycles/yr	13.0
Hoeksma et al., 1993	8.0-9.0	g NH_3/animal/day	8.5	119 days/cycle, 2.8 cycles/yr, 1 lb/453.6 g	6.2
Oosthoek et al, 1988	3	kg/animal/yr	3	2.2046 lb/kg	6.6
AVERAGE					**8.2**[a]

[a]The EF data points shown in this table have be rounded; therefore, the average of these EF data points does not exactly match the average EF presented in the table.

Table A-4

Calculation of the Ammonia Emission Factor for Scrape Barns at Dairy Operations

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Van Der Hoek, 1998	14.5	kg /animal/year	14.5	2.2046 lb/kg	32.0
Hugoson, 1999	7-13	g/LU/day	10	1 LU/500 kg LW, 1 lb/ 453.6 g, 612 kg/hd, 365 days/yr	9.85
Hugoson, 1999	1.7-4.4	L/hour-cow(500kg)	3.05	0.7714 g/L, 612 kg/hd, 24 hrs/day, 365 days/yr	55.6
Groot Koerkamp, 1998	1207	mg/hr/500 kg live weight	1207	612 kg/hd, 24 hrs/day, 365 days/yr, 1g/1000mg, 1lb/453.6	28.3
AVERAGE					**31.4**

Poultry Houses

The ammonia emission factors for broiler houses, dry layer houses, wet layer houses, and turkey houses are based on data identified from the literature review.

Broilers

The literature search identified eight applicable data points for broiler houses. Table A-5 presents these data points and the calculations used to estimate the emission factor.

Table A-5

Calculation of the Ammonia Emission Factor for Broiler Houses

Reference	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF (lb NH_3/yr/head)
Van Der Hoek, 1998	0.15	kg/animal/yr	2.2046 lb/kg	0.33
Tamminga, 1992	0.1	kg/broiler/yr	2.2046 lb/kg	0.22
Battye et al., 1994	0.065	kg/animal/yr	2.2046 lb/kg	0.14
Kroodsma et al., 1988	21.9	g/animal/fattening period	1 lb/453.6 g, 6 cycles/yr[a]	0.29
Groot Koerkamp et al., 1998	19.8	mg/hr/broilers housed in litter	24 hrs/day, 60 days/cycle,[1] 6 cycles/yr,[2] 1g/1,000 mg, 1 lb/453.6g	0.38
Groot Koerkamp et al., 1998	11.2	mg/hr/broilers housed in litter	24 hrs/day, 60 days/cycle,[2] 6 cycles/yr,[2] 1g/1,000 mg, 1 lb/453.6g	0.21
Groot Koerkamp et al., 1998	8.9	mg/hr/broilers housed in litter	24 hrs/day, 60 days/cycle,[2] 6 cycles/yr,[2] 1g/1,000 mg, 1 lb/453.6g	0.17
Groot Koerkamp et al., 1998	18.5	mg/hr/broilers housed in litter	24 hrs/day, 60 days/cycle,[2] 6 cycles/yr,[2] 1g/1,000 mg, 1 lb/453.6g	0.35
AVERAGE				**0.26**

[2] USDA NRCS. 2000. *Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States*. U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NCRS), Washington, DC.

Dry Layers

The literature search identified two applicable data points for dry layer houses. Table A-6 presents these data points and the calculations used to estimate the emission factor.

Table A-6

Calculation of the Ammonia Emission Factor for Dry Layer Houses

Ref No.	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF (lb NH_3/yr/AU)
Groot Koerkamp et al., 1998 and Groot Koerkamp, 1994	386	g/bird-year	1 lb/453.6 g	0.85
Valli et al., 1991	87	lb NH3/AU-yr	1 AU/100 head	0.87
AVERAGE				**0.86**

Wet Layers

The literature search identified four applicable data points for wet layer houses. Table A-7 presents these data points and the calculations used to estimate the emission factor.

Table A-7

Calculation of the Ammonia Emission Factor for Wet Layer Houses

Ref No.	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF (lb NH_3/yr/head)
Kroodsma et al., 1988	110	g/hen/yr	1 lb/453.6 g	0.24
Groot Koerkamp et al., 1998	83	g/bird-year	1 lb/453.6 g	0.18
Hartung and Phillips, 1994	83	g/hen/yr	1 lb/453.6 g	0.18
Hartung and Phillips, 1994	38.8	kg/500 kg LW (lb/500 lb LW)	3.98 lb/hd	0.31
AVERAGE				**0.23**

Turkeys

The literature search identified two applicable data points for turkey houses. Table A-8 presents these data points and the calculations used to estimate the emission factor.

Table A-8

Calculation of the Ammonia Emission Factor for Turkey Houses

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Van Der Hoek, 1998	0.48	kg/animal/yr	0.48	2.2046 lb/kg	1.06
Battye et al., 1994	0.429 - 0.639	kg/animal/yr	0.534	2.2046 lb/kg	1.18
AVERAGE					**1.12**

A.1.2.2 Hydrogen Sulfide

Houses with Deep-Pit Systems

The hydrogen sulfide emission factor for swine houses with deep-pit systems is based on data identified in the literature review. However, there were no applicable data points identified for veal houses with deep-pit systems; therefore, the hydrogen sulfide emission factor for swine houses with deep-pit systems was transferred to veal houses with deep-pit systems.

Swine

OAQPS's literature search identified six applicable data points for swine houses with deep-pit systems. Table A-9 presents these data points and the calculations used to estimate the emission factor.

Table A-9

Calculation of the Hydrogen Sulfide Emission Factor for Swine Houses with Deep-Pit Systems

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lbH_2S/yr/head)
Rochette et al., 2000	4	μg/s/animal (finishing)	4	1 min/3600 sec, 24 hrs/day, 119 days/cycle, 2.8 cycles/yr 1lb/$4.53x10^8$ μg	0.25
Ni et al., 2000a	150	mg/day/pig	150	119 days/cycle, 2.8 cycles/yr, 1 lb/453,600 mg	0.11
Ni et al., 2000b	0.873	g/500 kg LW-day	0.873	1 lb/453.6 g, 0.4536 kg/lb, 135 lb/hd, 119 days/cycle, 2.8 cycles/yr	0.08
Ni et al., 2000b	5.9	g/500 kg LW-day	5.9	1 lb/453.6 g, 0.4536 kg/lb, 135 lb/hd, 119 days/cycle, 2.8 cycles/yr	0.53
Ni et al., 2000b	6.7	g/500 kg LW-day	6.7	1 lb/453.6 g, 0.4536 kg/lb, 135 lb/hd, 119 days/cycle, 2.8 cycles/yr	0.60
Ni et al., 1998	7.0	g/500 kg LW-day	5.51	1 lb/453.6 g, 0.4536 kg/lb, 135 lb/hd, 119 days/cycle, 2.8 cycles/yr	0.50
AVERAGE					**0.40**

Veal

The hydrogen sulfide emission factor for veal houses with deep-pit systems is based on the percent loss of sulfur from swine houses with deep-pit systems. Swine operations have a sulfur excretion rate of 3.42 lb S/yr/head. Using Equation A-1, a loss of 0.40 lbs H_2S/yr/head (0.38 lb S/yr/head) from the confinement house represents 11.1 percent of the sulfur excreted per year. Using Equation A-2, and given that veal operations have a sulfur excretion rate of 7.14 lb S/yr/head, a loss of 0.72 lb S/yr/head (0.77 lb H_2S/yr/head) is expected at veal houses with deep-pit systems.

A.1.3 Lagoons and Ponds

Separate ammonia and hydrogen sulfide lagoon emission factors were calculated for each animal type to account for variation in emissions due to differences in the amount of nitrogen excreted and in waste management systems.

A.1.3.1 Ammonia

The ammonia emission factor for lagoons at swine operations is based on data identified from OAQPS's literature review. The ammonia emission factor for lagoons and ponds at dairies, beef feedlots, heifer, veal, and wet layer operations are transferred from swine.

Swine

The literature search identified nine applicable data points for swine houses with deep-pit systems. Table A-10 presents these data points and the calculations used to estimate the emission factor.

Dairy

The ammonia emission factors for lagoons at dairies are based on the percent loss of nitrogen from lagoons at swine operations. The percent loss of nitrogen represented by the swine lagoon emission factor was calculated using Equation A-3.

Table A-10

Calculation of the Ammonia Emission Factor for Lagoons at Swine Operations

Reference	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF (lb NH_3/yr/head)
Aneja et al., 2002	2.2	kg N/yr/head	2.2046 lb/kg, 17NH_3/14N	5.9
Koelliker and Miner, 1971	6.53	kg NH_3/yr/head	2.2046 lb/kg	14.4
Fulhage, 1998	64.7	Percentage of excreted nitrogen	56 lb N/yr-AU, 17NH_3/14N, 1 AU/2.5 head	17.6
Fulhage, 1998	77.2	Percentage of excreted nitrogen	56 lb N/yr-AU, 17NH_3/14N, 1 AU/2.5 head	21.0
Martin, 2002	8,210	kg/yr/500 AU	2.2046 lb/kg, 1 AU/2.5 head	14.5
Martin, 2002	5,602	kg/yr/500 AU	2.2046 lb/kg, 1 AU/2.5 head	9.9
Harper and Sharpe, 1998	0.96	kg NH_3/yr/head	2.2046 lb/kg	2.1
Harper and Sharpe, 1998	0.93	kg NH_3/yr/head	2.2046 lb/kg	2.1
Harper et al., 2000	0.99	g N/m^2-day	365 days/yr, 35,400 m^2/lagoon, 1 lb/453.6 g, 1,620,502 lb LW, 17 NH_3/14N	2.9
AVERAGE				**10.0**

$$\%\ \text{Loss of N}_{\text{lagoon}} = \frac{\text{Ammonia Lagoon Emission Rate}_{\text{swine}} \times \text{CF}}{\text{Nitrogen}_{\text{input}}} \times 100\% \qquad \text{(A-3)}$$

where:

% Loss of N_{lagoon}	=	Percentage of nitrogen entering the swine lagoon lost as ammonia
Ammonia Lagoon Emission $Rate_{swine}$	=	Ammonia emission factor for the swine lagoon (lb NH_3/yr/head)
CF	=	Conversion factor (14 N/17 NH_3).

It is estimated that 18.9 lb N/yr/head is excreted at swine operations. As shown in Table A-10, the swine lagoon emission factor is 10 lb NH_3/yr/head; therefore, using Equation A-3, the percentage of nitrogen lost from the lagoon as ammonia is:

$$= \frac{10 \text{ lb NH}_3\text{/yr/head} \times \frac{14 \text{ N}}{17 \text{ NH}_3}}{18.9 \text{ lb N/yr/head}} \times 100\%$$

$$= 43.6\%$$

Separate lagoon emission factors were calculated for dairies with and without settling basins. At dairies with settling basins, the nitrogen flushed from the confinement houses first flows through the settling basins before entering the lagoon, which removes 12 percent of the nitrogen. The percent loss of nitrogen from the lagoon, calculated in Equation A-3, was converted to emission factors in NH_3/year/head for lagoons at dairies using equations A-4 and A-5.

$$\text{Ammonia Lagoon Emission Rate}_{\text{dairy, no settling}} = \text{Nitrogen}_{\text{input}} \times \%\ \text{Loss of N}_{\text{lagoon}} \times \text{CF} \qquad \text{(A-4)}$$

where:

Ammonia Lagoon Emission $Rate_{dairy, no settling}$	=	Ammonia emission factor for lagoons at dairies without settling basins (lb NH_3/yr/head)
$Nitrogen_{input}$	=	Amount of nitrogen entering the lagoon from runoff and/or from the dairy confinement houses
% Loss of N $_{lagoon}$	=	Percentage of nitrogen entering lagoons at swine operations excreted as ammonia calculated in Equation A-3
CF	=	Conversion factor (14 N/17 NH_3).

$$\text{Ammonia Lagoon Emission Rate}_{\text{dairy, with settling}}$$

$$= ((\text{Nitrogen}_{\text{input, house}} \times \%\ \text{Loss of N}_{\text{settling}}) + \text{N}_{\text{input, runoff}}) \times \%\ \text{Loss of N}_{\text{lagoon}} \times \text{CF} \qquad \text{(A-5)}$$

where:

Ammonia Lagoon Emission Rate$_{\text{dairy, with settling}}$	=	Ammonia emission factor for lagoons at dairies with settling basins (lb NH_3/yr/head)
Nitrogen$_{\text{input, house}}$	=	Amount of nitrogen entering the lagoon from the dairy confinement houses
Nitrogen$_{\text{input, runoff}}$	=	Amount of nitrogen entering the lagoon in the runoff from the drylot at the dairy operation
% Loss of N$_{\text{settling}}$	=	Percentage of nitrogen entering lagoons removed by the settling basin (88%)
% Loss of N$_{\text{lagoon}}$	=	Percentage of nitrogen entering lagoons at swine operations excreted as ammonia calculated in Equation A-3
CF	=	Conversion factor (14 N/17 NH_3).

Although flush dairies and scrape dairies have the same nitrogen excretion rate, these two types of waste management systems manage the excreted nitrogen differently. Flush dairies transport the wastewater from both the milking parlor and the freestall barn to the lagoon. Scrape dairies transport only the wastewater from flushing the milking parlor to the lagoon. Table A-11 presents the nitrogen input to the lagoon from the confinement houses at scrape and flush dairies, with and without settling basins.

Table A-11

Nitrogen Input to Lagoons from Confinement Houses at Dairy Operations (lb/yr/head)

Animal Type	Excreted, Parlor	Excreted, Barn	Loss from Barn	Net Input to Lagoon
Flush	33.2	188.5	33.8	187.9
Scrape	33.2	188.5	33.8	33.2

Both scrape and flush dairies also send the runoff from the drylot to the lagoon. The same amount of nitrogen is excreted at the drylot at flush and scrape dairies. The amount of nitrogen in the runoff sent to lagoons therefore depends on the amount of precipitation received in each region. Table 2.1-2 in Section 2.1 of this report presents the amount of nitrogen in the runoff at dairies for each region.

After calculating the total nitrogen input to the lagoon, Equations A-4 and A-5 are used to calculate the ammonia emission factor for the lagoon. For example, given that 188.3 lb N/yr/head enters the lagoon from the milking parlor and freestall barn at a flush dairy, 11.93 lb N/yr/head enters the lagoon in the runoff in the Mid-Atlantic region, and 43.6 percent of the nitrogen entering lagoons at swine operations is lost as ammonia, the emission factor for a Mid-Atlantic flush dairy with a settling basin, using Equation A-5, is:

$$= ((187.9 \text{ lb N/yr/head x } 0.88) + 11.93 \text{ lb N/yr/head}) \text{ x } 0.436 \text{ x } 17 \text{ NH}_3/14 \text{ N}$$

$$= 93.9 \text{ lb NH}_3\text{/yr/head}$$

Beef and Heifer

A portion of the nitrogen excreted at drylots at beef feedlots and heifer operations is carried away in the runoff, which collects in the storage pond. Table 2.1-2 in Section 2.1 of this report presents the nitrogen content of the runoff by region. At operations without settling basins, all of the nitrogen in the runoff enters the pond, and the pond emission factor can be calculated using Equations A-3 and A-4. At operations with settling basins, the runoff first enters the settling basin, which removes 12 percent of the nitrogen. The remaining 88 percent of the nitrogen then enters the pond. The pond emission factor for beef feedlots with settling basins is calculated using Equation A-6.

$$\text{Ammonia Lagoon Emission Rate}_{\text{beef, with settling}}$$

$$= \text{Nitrogen}_{\text{input, runoff}} \times \% \text{ Loss of N}_{\text{settling}} \times \% \text{ Loss of N}_{\text{lagoon}} \times \text{CF} \qquad \text{(A-6)}$$

where:

Ammonia Lagoon Emission Rate$_{\text{beef, settling}}$	=	Ammonia emission factor for lagoons at beef feedlots with settling basins (lb NH_3/yr/head)
Nitrogen$_{\text{input, runoff}}$	=	Amount of nitrogen entering the lagoon in the runoff from the drylot at beef feedlots
% Loss of N$_{\text{settling}}$	=	Percentage of nitrogen entering lagoons removed by the settling basin (88%)
% Loss of N$_{\text{lagoon}}$	=	Percentage of nitrogen entering lagoons at swine operations excreted as ammonia calculated in Equation A-3
CF	=	Conversion factor (14 N/17 NH_3).

Veal

Flush veal operations have lagoons in the production area. At these operations, only the wastewater from flushing the barn is sent to the lagoon. In addition, it is assumed that all lagoon veal operations have a settling basin in place at baseline and under all regulatory options. Veal operations have a nitrogen excretion rate of 25.6 lb N/yr/head, and 4.5 lb N/yr/head is lost at the flush house. The remaining 21.1 lb N/yr/head flows into the settling basin before entering the lagoon. A lagoon emission factor for veal operations of 9.8 lb NH_3/yr/head was calculated using Equation A-7.

$$\text{Ammonia Lagoon Emission Rate}_{veal}$$

$$= \text{Nitrogen}_{input,\ house} \times \%\ \text{Loss of N}_{settling} \times \%\ \text{Loss of N}_{lagoon} \times \text{CF} \tag{A-7}$$

where:

Ammonia Lagoon Emission Rate$_{veal}$	=	Ammonia emission factor for lagoons at veal operations (lb NH_3/yr/head)
Nitrogen$_{input, house}$	=	Amount of nitrogen entering the lagoon from the veal confinement houses
% Loss of $N_{settling}$	=	Percentage of nitrogen entering lagoons removed by the settling basin (88%)
% Loss of N_{lagoon}	=	Percentage of nitrogen entering lagoons at swine operations excreted as ammonia calculated in Equation A-3
CF	=	Conversion factor (14 N/17 NH_3).

Wet Layers

At poultry operations using a wet layer system, waste is flushed out of the layer house and stored in a lagoon. It is assumed that wet layer poultry operations do not have settling basins. These operations have a nitrogen excretion rate of 1.15 lb N/yr/head. Of this total amount of nitrogen excreted per year, 0.19 lb N/year/head is lost from the confinement house. The remaining 0.96 lb N/yr/head enters the lagoon. Therefore, using Equations A-3 and A-4, a loss of 0.42 lb N/yr/head (0.51 lb NH_3/yr/head) can be expected from lagoons at poultry operations with wet layer systems.

A.1.3.2 Hydrogen Sulfide

The hydrogen sulfide emission factor for lagoons at swine operations is based on data identified by the literature review. The hydrogen sulfide emission factors for lagoons at dairies, veal, and wet layer operations are transferred from swine.

Swine

The literature search identified three applicable data points for lagoons at swine operations. Table A-12 presents these data points and the calculations used to estimate the emission factor.

Table A-12

Calculation of the Hydrogen Sulfide Emission Factor for Lagoons at Swine Operations

Reference	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF ($lb\ H_2S/yr/head$)
Jacobson et al., 1999	4.84	lb H_2S/yr/AU	1 AU/2.5 head	1.936
Grelinger and Page, 1999	2.89	lb H_2S/yr/AU	1 AU/2.5 head	1.156
Martin, 2002	1.57	lb H_2S/yr/AU	1 AU/2.5 head	0.628
AVERAGE				**1.24**

Dairy

The hydrogen sulfide emission factors for lagoons at dairies are based on the percent loss of sulfur from lagoons at swine operations. Using Equation A-3 and given that swine operations have a sulfur excretion rate of 3.42 lb S/yr/head, a loss of 1.24 lb H_2S/yr/head (1.17 lb S/yr/head) from the confinement house represents 34.1 percent of the sulfur excreted per year.

Flush dairies transport the wastewater from both the milking parlor and the freestall barn to the lagoon. Scrape dairies only transport the wastewater from flushing the milking parlor to the lagoon. Table A-13 presents the sulfur input to the lagoon from the confinement houses at scrape and flush dairies. At flush and scrape dairies with settling basins, 50 percent of the sulfur entering the lagoon from the confinement houses is removed.

Table A-13

Sulfur Input to Lagoons from Confinement Houses at Dairy Operations (lb/yr/head)

Animal Type	Excreted, parlor	Excreted, barn	Net Input to Lagoon
Flush	3.8	21.3	25.1
Scrape	3.8	NA	3.8

NA - Not applicable.

After calculating the total sulfur input to the lagoon, the hydrogen sulfide emission factors for lagoons at dairy operations are calculated using Equations A-3, A-4, and A-5.

Veal

Flush veal operations have lagoons in the production area. At these operations, only the wastewater from flushing the barn is sent to the lagoon. In addition, it is assumed that all lagoon veal operations have a settling basin in place at baseline and under all regulatory options. Veal operations have a nitrogen excretion rate of 6.5 lb S/yr/head; all of the sulfur excreted at the confinement barn enters the solids separators. Using Equations A-3, and A-7, a loss of 1.1 lb S/yr/head (1.2 lb H_2S/yr/head) is expected from lagoons at veal operations.

Wet Layers

At poultry operations using a wet layer system, waste is flushed out of the layer house and stored in a lagoon. It is assumed that wet layer poultry operations do not have settling basins. Wet layer poultry operations have a sulfur excretion rate of 0.20 lb S/yr/head; all of the sulfur excreted at poultry operations with wet layer systems enters the lagoon. Using Equations A-3 and A-4, a loss of 0.066 lb S/yr/head (0.07 lb H_2S/yr/head) is expected from lagoons at poultry operations with wet layer systems.

A.2 Example Ammonia Calculation

This example presents the calculations of ammonia emission factors and the annual model farm emissions of ammonia from a Flush Dairy, Central, Large 1 operation (1,430 mature cows, 429 heifers, 429 calves).

A.2.1 Baseline Emissions

Emissions are calculated for four types of manure management components: drylots, confinement houses, lagoons, and stockpiles. The first set of calculations presents the emissions for a flush dairy with solids separation in place, and the second set presents a flush dairy without solids separation.

A.2.1.1 Flush Dairy with Solids Separation

Drylot

Ammonia emissions from dairy drylots where heifers and calves are housed are calculated by determining the amount of nitrogen in the manure excreted at the drylot using Equation A-8.

$$\text{Nitrogen Excreted}_{\text{drylot}}\ (\text{lb/day}) = \text{Weight (lb/head)} \times \text{Nitrogen}_{\text{excreted}}\ (\text{lb/day/1,000 lb animal}) \times \text{Number of Head} \quad \text{(A-8)}$$

For the flush dairy model farm (which has an equal number of heifers and calves), the amount of nitrogen excreted at the drylot is:

$$= 550 \text{ lb heifer / head} \times 0.31 \text{ lb N / day / 1000-lb} \times 429 \text{ head}$$
$$+ 350 \text{ lb calf / head} \times 0.27 \text{ lb N / day / 1000-lb} \times 429 \text{ head}$$
$$= 113.7 \text{ lb N / day}$$

Using Equation A-9, the amount of nitrogen excreted at the drylot is multiplied by an emission factor of 45 percent to determine the amount of nitrogen lost to runoff and air emissions.

$$\text{Manure Nitrogen}_{\text{lost}} \text{ (lb/day)} = \text{Nitrogen Excreted}_{\text{drylot}} \times 0.45 \qquad \text{(A-9)}$$

$$= 113.7 \text{ lb N / day} \times 0.45$$

$$= 51.2 \text{ lb N / day}$$

The amount of nitrogen emitted from the drylot as air emissions is determined using Equation A-10. Given that the amount of nitrogen in runoff[3] (lb/year/head) = 3.69, the manure nitrogen emitted from the drylot as air emissions is:

$$\text{Nitrogen Emitted}_{\text{drylot}} \text{ (lb/year/head)} = (\text{Manure Nitrogen}_{\text{lost}} \times 365 \frac{\text{days}}{\text{year}} \times \frac{1}{\text{Head}}) - \text{Nitrogen Runoff}_{\text{drylot}} \qquad \text{(A-10)}$$

$$= (51.2 \text{ lb N / day}) \times (365 \text{ days / year}) \times (1 / 1{,}430 \text{ head}) - (3.69 \text{ lb N / year / head})$$

$$= 9.37 \text{ (lb N / year / head)}$$

The emissions are converted to ammonia by multiplying by a conversion factor:

$$= (9.37 \text{ lb N / year / head}) \times (17\ NH_3 / 14\ N)$$

$$\boxed{= 11.38 \text{ lb } NH_3 \text{ / year / head}}$$

[3] 2002. EPA. *Cost Methodology Report for Animal Feeding Operations.*

House

Mature dairy cows are housed in freestall barns where 85 percent of their manure is excreted. The remaining 15 percent of manure is excreted in the milking parlor. The emission factor for nitrogen losses from a confinement barn is 17.9 percent, as shown in Table 2.1-4 of this report. Equation A-11 is used to calculate the emission rate for confinement houses.

$$\text{House Emission Rate (lb/year/head)} = \text{Manure Nitrogen (lb/year/head)} \text{ x } \frac{17\ NH_3}{14\ N} \text{ x Emission Factor} \qquad \text{(A-11)}$$

where:

$$\text{Manure Nitrogen (lb/year/head)}$$

$$= \frac{1{,}350 \text{ lbs/head x } 0.45 \text{ lbs N/day}}{1{,}000 \text{ lbs}} \times \frac{365 \text{ days}}{\text{year}} \times 0.85$$

$$= 188.5 \text{ lbs N/year/head}$$

The House Emission Rate, converted to pounds of ammonia per head per year is:

$$= (188.5 \text{ lb N / year / head}) \times (17\ NH_3 / 14\ N) \times 0.179$$

$$\boxed{= 40.97 \text{ lb } NH_3 \text{ / year / head}}$$

Lagoons

The manure from the freestall barns is flushed and the wastewater along with the waste from the milking parlor are stored and managed in an anaerobic lagoon. Equation A-12 is used to calculate the ammonia emission rate for lagoons with solids separation in place, assuming 88 percent of the nitrogen from the separator enters the lagoon and 43.6 percent of the nitrogen in the lagoon is emitted as ammonia, where N_{input} equals waste entering the solids separator.

$$\text{Lagoon Emission Rate}_{\text{with separator}} \text{ (lb/year/head)} = N_{lagoon} \text{ (lb/year/head) x } 0.436 \text{ x } \frac{17\ NH_3}{14\ N} \qquad \text{(A-12)}$$

The amount of nitrogen entering the lagoon is calculated using Equation A-13, where the amount of nitrogen in runoff[4] (lb / year / head) is equal to 3.69 .

$$N_{lagoon} \text{ (lb/year/head)} = [N_{input} + \text{Runoff] (lb/year/head)} \qquad \text{(A-13)}$$

N_{input} is calculated using Equation A-14.

$$N_{input} = \frac{[N_{excreted,\ barn} - N_{emitted,\ barn} + N_{excreted,\ milk\ parlor}] \text{ (lb/year)}}{\text{Number Head}} \qquad \text{(A-14)}$$

[4]2002. EPA. *Cost Methodology Report for Animal Feeding Operations.*

$$= \frac{738.4 \text{ lbs N / day } - 132.2 \text{ lbs N / day } + 130.3 \text{ lbs N day}}{1{,}430 \text{ head mature cows}} \times \frac{365 \text{ days}}{\text{year}}$$

$$= 188.0 \text{ lbs N / year / head}$$

ERG assumes that 12 percent of the input nitrogen is separated by the solids separator and 88 percent goes to the lagoon. Therefore, using Equation A-13, N_{lagoon} (lb N/year/head) is equal to:

$$= 188.0 \text{ lb N / year / head} \times 0.88 + 3.69 \text{ lb N / year / head}$$

$$= 169.13 \text{ lb N / yr / head}$$

Using Equation A-12 the Lagoon Emission Rate is calculated as follows:

$$= (169.13 \text{ lb N / year / head}) \times (0.436) \times (17 \text{ NH}_3 / 14 \text{ N})$$

$$\boxed{= 89.55 \text{ lb NH}_3 \text{ / year / head}}$$

Stockpile

Equation A-15 is used to calculate the ammonia emission rate from stockpiles with solids separation. The 12 percent removal factor is based on the assumption that 12 percent of nitrogen in manure is removed with solids during solids separation. Stockpile emission rates are based on information obtained in a literature review. The stockpile ammonia emission rate is based on information from a literature review[5], which indicates that 20 to 40 percent of nitrogen is lost from solids manure storage. For this analysis, an emission factor of 20 percent was used.

$$\text{Stockpile Emission Rate (lb / year / head)} = N_{stockpile} \text{ (lb / year / head)} \times 0.20 \times \frac{17 \text{ NH}_3}{14 \text{ N}} \quad \text{(A-15)}$$

where:

$$N_{stockpile} \text{ (lbs / year / head)} = N_{input} \times 0.12$$

[5]Sutton, A.L., D.D. Jones, B.C. Joern, and D.M. Huber. 2001. Animal Manure as a Plant Resource. http://www.agcom.purdue.edu/AgCom/Pubs/ID/ID-101.html. Purdue University. West Lafayette, IN.

Using Equation A-15, the Stockpile Emissions Factor (lbs NH_3/year/head) is:

$$= (22.56 \text{ lb N / year / head}) \times (0.20) \times (17 \text{ NH}_3 \text{ / 14 N})$$

$$\boxed{= 5.48 \text{ lb NH}_3 \text{ / year / head}}$$

Model Farm Emissions

The model farm emissions are calculated as the sum of the emissions for each manure management component per head multiplied by the average number of head at the model farm using Equation A-16. For this example, the emission per model farm with solids separation includes emissions from the drylot, barn, lagoon and stockpile.

$$\text{Emissions per Model Farm} = \sum \frac{\text{Emissions}}{\text{Head}} \times \frac{\text{Average Head}}{\text{Model Farm}} \qquad \text{(A-16)}$$

Using Equation A-16, the model farm emissions for a Flush Dairy, Central, Large 1 operation with solids separation are:

$$= \frac{((11.38 + 40.97 + 89.55 + 5.48) \text{ lbs NH}_3 \text{ / year / head})}{2{,}000 \text{ lbs / ton}} \times 1{,}430 \text{ head}$$
$$= 105.4 \text{ tons NH}_3 \text{ / year}$$

A.2.1.2 Flush Dairy without Solids Separation

When solids separation technology is not in place, drylot and house emissions rates are the same as those in flush dairies with solids separation. However, the emissions rate for lagoons is different because all from the barn and parlor are flushed to the lagoon, as shown below. Note that stockpiles are not a component of flush dairies without solids separation.

Lagoons

Equation A-17 is used to calculate the ammonia emissions factor for lagoons where solids separation is not in place.

$$\text{Lagoon Emission Rate}_{\text{without separator}} \text{ (lb / year / head)} = N_{\text{lagoon}} \text{ (lb / year / head)} \times 0.436 \times \frac{17 \text{ NH}_3}{14 \text{ N}} \qquad \text{(A-17)}$$

Using Equation A-13:

$$N_{\text{lagoon}} \text{ (lbs N / year / head)} = [188.0 + 3.69] \text{ (lbs N / year / head)}$$
$$= 191.69 \text{ lb N / year / head}$$

Using Equation A-17, the Lagoon Emissions Rate (lbs NH_3/year/head) =

$$= (191.69 \text{ lb N / year / head}) \times (0.436) \times (17 \text{ NH}_3 / 14 \text{ N})$$

$$\boxed{= 101.48 \text{ lb NH}_3 \text{ / year / head}}$$

Model Farm

Using Equation A-16, the emissions per model farm where solids separation is not in place includes emissions from the drylot, barn, and lagoon.

$$= \frac{((11.38 + 40.97 + 101.48) \text{ lbs NH}_3 \text{ / year / head})}{2{,}000 \text{ lbs / ton}} \times 1{,}430 \text{ head}$$
$$= 109.9 \text{ tons NH}_3 \text{ / year}$$

Total Baseline Emissions for Large Dairy Flush Operations

The emission rate for the industry is calculated as the emission per model farm multiplied by the number of facilities. Because this example includes both model farms with solids separation and those without, frequency factors are included in this calculation. It is assumed that 33 percent of the flush dairy operations have solid separators and that 67 percent do not.

$$= (105.4 \text{ tons / year} \times 0.33 \times 301 \text{ dairy flush facilities}) +$$
$$(109.9 \text{ tons / year} \times (1 - 0.33) \times 301 \text{ dairy flush facilities})$$
$$= 32{,}633 \text{ tons NH}_3 \text{ / year}$$

A.2.2 Emissions for Options 1-4, 6 and 7

Under Options 1-4, 6 and 7, it is assumed that all operations have solids separation in place. Therefore, the emission per model farm is identical to that calculated in the flush dairy with solids separation baseline calculation. However, the total industry emissions calculation is different from baseline because model farms without solids separation are not included and frequency factors are not applied.

Total Emissions for Options 1-4, 6, 7 for Large Dairy Flush Operations

$$= 105.4 \text{ tons / year} \times 301 \text{ facilities}$$
$$= 31{,}725 \text{ tons NH}_3 \text{ / year}$$

A.2.3 Emissions for Option 5A

Option 5A assumes that all solids removed by solids separation or scraped from the drylot are composted. The nitrogen remaining on the drylot is 55 percent of the nitrogen excreted. The drylot, confinement house, and lagoon portions of this calculation are the same as those for flush dairies with solids separation at baseline as shown in Equation A-18. It is assumed that 30 percent of the nitrogen in the compost is emitted as ammonia.[6]

Compost

$$\text{Compost Emission Rate (lb / year / head)} = N_{compost}\text{ (lb / year / head)} \times 0.30 \times \frac{17\ NH_3}{14\ N} \quad \text{(A-18)}$$

where:

$$\begin{aligned} N_{compost}\text{ (lbs N / year / head)} &= N_{input} \times 0.12 + (N_{drylot} \times 365\text{ days / year} \times 1/1430\text{ head}) \times 0.55 \\ &= (188.0\text{ lb / year / head} \times 0.12) + (29.0\text{ lb N / year / head} \times 0.55) \\ &= 38.5\text{ lb N / year / head} \end{aligned}$$

Using Equation A-18, the Compost Emissions Rate (lbs NH_3/year/head) =

$$= (38.5\text{ lb N / year / head}) \times (0.30) \times (17\ NH_3 / 14\ N)$$

$$\boxed{= 14.03\text{ lb } NH_3\text{ / year / head}}$$

Total Model Farm Emissions for Option 5A

Using Equation A-16, the model farm emissions for Option 5A include emissions from the drylot, barn, lagoon, and compost pile.

$$\begin{aligned} &= \frac{((11.38 + 40.97 + 89.55 + 14.03)\text{ lbs } NH_3\text{ / year / head})}{2{,}000\text{ lbs / ton}} \times 1{,}430\text{ head} \\ &= 111.4\text{ tons } NH_3\text{ / year} \end{aligned}$$

Total Option 5A Emissions for Large Dairy Flush Operations

The industry emission rate is the product of the emission per model farm and the number of facilities:

$$\begin{aligned} &= 111.4\text{ tons / year} \times 301\text{ facilities} \\ &= 33{,}519\text{ tons } NH_3\text{ / year} \end{aligned}$$

A.3 Example Hydrogen Sulfide Calculation

This example presents the calculations of annual model farm emissions of hydrogen sulfide from a Flush Dairy, Central, Large 1 operation (1,430 mature cows, 429 heifers, 429 calves). For the reasons discussed in Section 2.1, hydrogen sulfide emission rates are

[6]Eghball, B., J. Power, J. Gilley, and J. Doran. 1997. "Waste Management - Nutrient, Carbon, and Mass Loss During Composting of Beef Cattle Feedlot Manure." *Journal of Environmental Quality*. Vol 26: Pp. 189-193.

assumed to be zero for all components except lagoons. Therefore, only the equations and calculations for lagoons are presented in this appendix.

A.3.1 Baseline Emissions

The first calculation evaluates the emission rate from a lagoon for a flush dairy with solids separation in place, and the second address a flush dairy without solids separation.

A.3.1.1 Flush Dairy with Solids Separation

Lagoon

It is assumed that the solids separator removes 50 percent of the waste and that 34.1 percent of the sulfur in the lagoon is converted to hydrogen sulfide as shown in Equation A-19, where S_{input} equals sulfur excreted in the barn and milking center.

$$\text{Lagoon Emission Rate}_{separator}\ (\text{lb / year / head}) = S_{input}\ (\text{lb / year / head}) \times 0.50 \times 0.341 \times \frac{17\ H_2S}{16\ S} \quad \text{(A-19)}$$

where:

S_{input} (lb S/year/head) =

$$= \frac{98.5 \text{ lbs S / day}}{1{,}430 \text{ head manure cows}} \times \frac{365 \text{ days}}{\text{year}}$$
$$= 25.1 \text{ lb S / year / head}$$

Therefore, the Lagoon Emission Rate (lb H_2S/year/head) is:

$$= (25.1 \text{ lb S / year / head}) \times (0.50) \times (0.341) \times \left(\frac{17\ H_2S}{16\ S}\right)$$

$$\boxed{= 4.56 \text{ lb S / year / head}}$$

Model Farm

Using Equation A-16, the model farm emission rate where solids separation is in place is:

$$= \frac{4.60 \text{ lbs } H_2S \text{ / year / head}}{2{,}000 \text{ lbs / ton}} \times 1{,}430 \text{ head}$$

$$= 3.26 \text{ tons } H_2S \text{ / year}$$

A.3.1.2 Flush Dairy without Solids Separation

Lagoon

The lagoon emission rate for a flush dairy without solids separation is calculated using Equation A-20.

$$\text{Lagoon Estimate Rate}_{(sep)}\ (lb / year / head) = S_{input}\ (lb / year / head) \times 0.341 \times \frac{17\ H_2S}{16\ S} \quad \text{(A-20)}$$

Therefore, the Lagoon Emission Rate (lb H_2S/year/head) =

$$= 25.1\ lbs\ S / year / head \times 0.341 \times \frac{17\ H_2S}{16\ S}$$

$$\boxed{= 9.11\ lb\ H2S / year / head}$$

Model Farm

Using Equation A-6, the model farm emission rate where solids separation is not in place is:

$$= \frac{9.11\ lbs\ H_2S / year / head}{2{,}000\ lbs / ton} \times 1{,}430\ head$$

$$= 6.51\ tons\ H_2S / year$$

Total Baseline Emissions for Large Dairy Flush Operations

The emission rate for the industry is calculated as the emission per model farm multiplied by the number of facilities. Because this example includes both model farms with solids separation and those without, frequency factors are included in this calculation. It is assumed that 33 percent of the dairy operations have solid separators and that 67 percent do not.

$$= (3.26\ tons / year \times 0.33 \times 301\ facilities) + (6.51\ tons / year \times (1 - 0.33) \times 301\ facilities)$$
$$= 1{,}637\ tons\ H_2S / year$$

A.3.2 Emissions for Options 1-7

For Options 1-7, it is assumed that all operations have solids separation in place. Therefore, the total model farm emission rate is identical to that calculated in the flush dairy with solids separation baseline calculation. However, the total industry emissions calculation is different from baseline because model farms without solids separation are not included and frequency factors are not applied.

<u>Total Emissions for Options 1-7 for Large Dairy Flush Operations.</u>

$$= 3.26 \text{ tons/year} \times 301 \text{ facilities}$$
$$= 990 \text{ tons } H_2S\text{/year}$$

Appendix B

Detailed Calculations for Air Emissions from Animal Confinement and Manure Management Systems - Greenhouse Gas Emissions

Introduction

Appendix B presents example calculations for methane and nitrous oxide emissions from manure management systems. These calculations follow the methodology presented in Section 2.2 of this report. All greenhouse gas emissions are reported in units of Tg-CO_2 equivalent, which normalizes all reported emissions to carbon dioxide. The greenhouse warming potential of methane is 21 times that of carbon dioxide, whereas nitrous oxide is 310 times that of carbon dioxide.

Example Methane Calculation:

ERG calculates the annual model farm emissions for methane using Equations B-1 through B-3, shown below. First, ERG uses Equation B-1 to estimate the emissions per head for each manure management component (e.g., drylot, pond, confinement house). Next, ERG uses Equation B-2 to calculate weighted emissions based on the percent of operations that have each component in place, and summed for all the components present at the model farm. Finally, ERG uses Equation B-3 to calculate model farm emissions by multiplying the weighted emissions per head by the average number of head at the model farm (presented in Section 1.0 of the report).

$$\text{Emission per Head}_{\text{component}} = \frac{\text{VS excreted}}{\text{head per day}} \text{ x } \frac{\text{365 days}}{\text{year}} \text{ x } B_o \text{ x } \frac{\text{0.67 kg } CH_4}{m^3 \ CH_4} \text{ x } MCF_{\text{component}} \qquad \text{(B-1)}$$

$$\text{Emission per Head}_{\text{model farm}} = \sum \text{Emission per Head}_{\text{component}} \text{ x Frequency Factor}_{\text{component}} \qquad \text{(B-2)}$$

$$\text{Emission per Model Farm} = \text{Emission per Head}_{\text{model farm}} \text{ x } \frac{\text{Number of Head}}{\text{Model Farm}} \qquad \text{(B-3)}$$

This example presents the calculations of annual model farm emissions of methane from a Beef, Central, Large 2 CAFOs.

Baseline Emissions

Based on the model farm definition for beef feedlots, all animals are housed on drylots. For baseline, ERG estimates that all Large and 50 percent of Medium CAFOs have a waste storage pond for the control of runoff. Using data provided by USDA, ERG further estimates the type of waste management systems currently in place at baseline at Large and Medium CAFOs that have “high,” “medium,” and “low” requirements. “High” requirements are assigned to 25 percent of the operations, “medium” requirements are assigned to 50 percent of the operations, and “low” requirements are assigned to 25 percent of the operations. These requirements are discussed in more detail in the cost methodology report.[1] For Large beef CAFOs, it is estimated that 60% of the farms with "low" requirements, 40% of the farms with "medium" requirements, and 0% of the farms with "high" requirements have a settling basin in place prior to the runoff pond. Therefore, emissions are calculated for three types of manure management components: drylots, runoff ponds without solids separation, and runoff ponds with solids separation.

Drylot Emissions (per head):

The methane emissions from the drylot are estimated using Equation B-1, where $B_o = 0.33\ m^3\ CH_4$ / kg VS and the drylot MCF = 0.015.

$$= \frac{5.44\ \text{kg/day VS}}{1{,}000\ \text{kg}} \times \frac{398\ \text{kg}}{\text{head}} \times \frac{365\ \text{days}}{\text{year}} \times \frac{0.33\ \text{m}^3\ \text{CH}_4}{\text{kg VS}} \times \frac{0.67\ \text{kg CH}_4}{\text{m}^3\ \text{CH}_4} \times 0.015$$

$$= 2.62\ \text{kg CH}_4\text{/yr/head}$$

Pond without Settling Basin Emissions (per head):

To estimate emissions from a pond without solids separation, ERG estimated the addition of volatile solids to the pond from runoff. From the cost methodology report, ERG estimated that 2,242,228 kg/yr of solids are added to the pond from runoff from a Beef, Central, Large 2 CAFO. Assuming the runoff solids have the same characteristics as manure, ERG first estimated the amount of volatile solids added to the pond per head.

$$= \frac{2{,}242{,}228\ \text{kg runoff solids/yr}}{\text{model farm}} \times \frac{\text{model farm}}{25{,}897\ \text{head}} \times \frac{\text{year}}{365\ \text{days}} \times \frac{5.44\ \text{kg VS/day}}{1{,}000\ \text{kg animal}} \times \frac{1{,}000\ \text{kg animal}}{63\ \text{kg manure/day}}$$

$$= 0.02\ \text{kg VS/day/head}$$

Next, the methane emissions from the pond are estimated using Equation B-1, where $B_o = 0.33\ m^3\ CH_4$ / kg VS and the pond MCF = 0.29.

$$= \frac{0.02\ \text{kg VS/day}}{\text{head}} \times \frac{365\ \text{days}}{\text{year}} \times \frac{0.33\ \text{m}^3\ \text{CH}_4}{\text{kg VS}} \times \frac{0.67\ \text{kg CH}_4}{\text{m}^3\ \text{CH}_4} \times 0.29$$

$$= 0.479\ \text{kg CH}_4\text{/yr/head}$$

[1] U.S. EPA. 2002a. *Cost Methodology Report for Animal Feeding Operations*. Washington, DC. December 2002.

Pond with Settling Basin Emissions (per head):

To estimate emissions from a pond with solids separation, ERG estimated the addition of volatile solids to the pond from runoff following the solids separation step. From the cost methodology report, ERG estimated that 2,242,228 kg/yr of solids are added to the settling basin from runoff from a Beef, Central, Large 2 CAFO. Assuming the runoff solids have the same characteristics as manure and the settling basin has a 50 percent efficiency, ERG estimates the amount of volatile solids added to the pond per head and estimates the methane emissions from the pond using Equation B-1, where $B_o = 0.33\ m^3\ CH_4$ / kg VS and the pond MCF = 0.29.

$$= \frac{0.02\ \text{kg VS/day}}{\text{head}} \times 0.50\ \text{efficiency} \times \frac{365\ \text{days}}{\text{year}} \times \frac{0.33\ \text{m}^3\ \text{CH}_4}{\text{kg VS}} \times \frac{0.67\ \text{kg CH}_4}{\text{m}^3\ \text{CH}_4} \times 0.29$$

$$= 0.24\ \text{kg CH}_4\text{/yr/head}$$

Weighted Sum of Component Emissions

Using Equation B-2, ERG calculates the weighted average emissions per head for the model farm. For a Beef, Central, Large 2 CAFO with "low" requirements, it is assumed that all operations have a drylot and a waste storage pond in place. In addition, 60 percent of the operations have a solids separator prior to the runoff pond.

$$\text{Emission per Head}_{\text{model farm, low}} = (\text{Drylot} \times 100\%) + (\text{Pond w/out settling} \times 40\%) + (\text{Pond w/settling} \times 60\%)$$

For our example calculation, the weighted emissions per head at a "low requirement" operation are:

$$= (2.62\ \text{kg CH}_4\text{/year} \times 100\%) + (0.479\ \text{kg CH}_4\text{/year} \times 40\%) + (0.24\ \text{kg CH}_4\text{/year} \times 60\%)$$

$$= 2.96\ \text{kg CH}_4\text{/year}$$

The weighted emissions are calculated in a similar fashion for "medium" (3.05 kg CH_4/yr) and "high" (3.10 kg CH_4/yr) requirement facilities. The overall weighted emission per head is estimated as 25 percent of the "low" emission, 50 percent of the "medium" emission, and 25 percent of the "high" emission, or 3.04 kg CH_4/yr.

Total Model Farm Emissions for Baseline

The model farm emissions are calculated as the weighted emissions per head multiplied by the average number of head at the model farm.

$$\text{Emission per Model Farm, low} = \frac{\text{Weighted Emissions}}{\text{Head}} \times \frac{\text{Average Head}}{\text{Model Farm}}$$

For our example calculation, the model farm emissions are:

$$= \frac{3.04 \text{ kg } CH_4\text{/year}}{\text{head}} \times \frac{25{,}897 \text{ head}}{\text{Model Farm}}$$

$$= 78{,}702 \text{ kg } CH_4\text{/year}$$

Emissions for Regulatory Options 1-4 and 7

Under Options 1-4 and 7, it is assumed that all CAFOs have a waste storage pond with settling basin in place. Therefore, when estimating total model farm emissions, the frequency factor for CAFOs having a pond with settling basin is 100%, and the frequency factor for CAFOs having a pond with no settling basin is 0%. The drylot portion of this calculation is the same as baseline.

<u>Weighted Sum of Component Emissions</u>

Using Equation B-2, ERG calculates the weighted average emissions per head for the model farm.

$$\text{Emission per Head}_{\text{model farm}} = (\text{Drylot} \times 100\%) + (\text{Pond w/out settling} \times 0\%) + (\text{Pond w/settling} \times 100\%)$$

For our example calculation, the weighted emissions per head are:

$$= (2.62 \text{ kg } CH_4\text{/year} \times 100\%) + (0.479 \text{ kg } CH_4\text{/year} \times 0\%) + (0.24 \text{ kg } CH_4\text{/year} \times 100\%)$$

$$= 2.86 \text{ kg } CH_4\text{/year}$$

<u>Total Model Farm Emissions for Options 1-4, 7</u>

The model farm emissions are calculated as the weighted emissions per head multiplied by the average number of head at the model farm.

$$\text{Emission per Model Farm} = \frac{\text{Weighted Emissions}}{\text{Head}} \times \frac{\text{Average Head}}{\text{Model Farm}}$$

For our example calculation, the model farm emissions are:

$$= \frac{2.86 \text{ kg } CH_4\text{/year}}{\text{head}} \times \frac{25{,}897 \text{ head}}{\text{Model Farm}}$$

$$= 74{,}047 \text{ kg } CH_4\text{/year}$$

Emissions for Regulatory Option 5A

Option 5A assumes that all solids removed by the settling basin and all solids scraped from the drylot are composted. The drylot and pond with basin portions of this calculation are the same as those for regulatory Options 1-4 and 7.

Compost Emissions (per head):

To estimate emissions from a compost pile, ERG estimated the addition of volatile solids to the pile using data from literature. As discussed in Section 2.2 of this report, ERG estimates that 564.6 pounds of volatile solids per ton of manure excreted is present in the compost pile at a Beef, Central, Large 2 operation. ERG estimates the amount of volatile solids added to the compost pile per head and estimates the methane emissions from the pond using Equation B-1, where $B_o = 0.33 \text{ m}^3 \text{ } CH_4$ / kg VS and the compost MCF = 0.01.

$$= \frac{44{,}200 \text{ tons manure compost/yr}}{\text{model farm}} \times \frac{564.61 \text{ lb VS to compost}}{\text{ton manure}} \times \frac{\text{kg}}{2.20462 \text{ lb}} \times \frac{\text{year}}{365 \text{ days}} \times \frac{1}{25{,}897 \text{ head}}$$

$$= 1.198 \text{ kg VS to compost/day/head}$$

$$= \frac{1.198 \text{ kg VS to compost/day}}{\text{head}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{0.33 \text{ m}^3 \text{ } CH_4}{\text{kg VS}} \times \frac{0.67 \text{ kg } CH_4}{\text{m}^3} \times 0.01$$

$$= 0.966 \text{ kg } CH_4\text{/year/head}$$

Weighted Sum of Component Emissions

Using Equation B-2, ERG calculates the weighted average emissions per head for the model farm.

$$\text{Emission per Head}_{\text{model farm}} = (\text{Drylot} \times 100\%) + (\text{Compost} \times 100\%) + (\text{Pond w/settling} \times 100\%)$$

For our example calculation, the weighted emissions per head are:

$$= (2.62 \text{ kg } CH_4/\text{year} \times 100\%) + (0.966 \text{ kg } CH_4/\text{year} \times 100\%) + (0.24 \text{ kg } CH_4/\text{year} \times 100\%)$$

$$= 3.83 \text{ kg } CH_4/\text{year}$$

Total Model Farm Emissions for Option 5A

The model farm emissions are calculated as the weighted emissions per head multiplied by the average number of head at the model farm.

$$\text{Emission per Model Farm} = \frac{\text{Weighted Emissions}}{\text{Head}} \times \frac{\text{Average Head}}{\text{Model Farm}}$$

For our example calculation, the model farm emissions are:

$$= \frac{3.83 \text{ kg } CH_4/\text{year}}{\text{head}} \times \frac{25{,}897 \text{ head}}{\text{Model Farm}}$$

$$= 99{,}074 \text{ kg } CH_4/\text{year}$$

Industry-level results for each threshold considered are simply calculated as the model farm results multiplied by the number of facilities (as defined in Section 1).

Example Nitrous Oxide Calculation:

ERG calculates the annual model farm emissions for nitrous oxide using Equations B-2 through B-4. First, Equation B-4 is used to estimate the emissions per head for each manure management component (e.g., drylot, pond, confinement house). Next, ERG uses Equation B-2 to calculate weighted emissions based on the percent of operations that have each component in place, and summed for all the components present at the model farm. Finally, ERG calculates model farm emissions using Equation B-3 by multiplying the weighted emissions per head by the average number of head at the model farm (presented in Section 1.0 of the report).

$$\text{Emission per Head} = \frac{N_{ex}}{\text{head}} \times 365 \text{ days} \times EF \times \frac{44 \text{ } N_2 0}{28 \text{ N}} \qquad \text{(B-4)}$$

This example presents the calculations of annual model farm emissions of nitrous oxide from a Beef, Central, Large 2 operation.

Baseline Emissions

Based on the model farm definition for beef feedlots, all animals are housed on drylots. For baseline, ERG estimates that all Large and 50 percent of Medium CAFOs have a waste storage pond for the control of runoff. Using data provided by USDA, ERG further estimates the type of waste management systems currently in place at baseline at Large and Medium CAFOs that have “high,” “medium,” and “low” requirements. “High” requirements are assigned to 25 percent of the operations, “medium” requirements are assigned to 50 percent of the operations, and “low” requirements are assigned to 25 percent of the operations. These requirements are discussed in more detail in the cost methodology report.[2] For Large beef CAFOs, it is estimated that 60% of the farms with “low” requirements, 40% of the farms with “medium” requirements, and 0% of the farms with “high” requirements have a settling basin in place prior to the runoff pond. Therefore, emissions are calculated for three types of manure management components: drylots, runoff ponds without solids separation, and runoff ponds with solids separation.

Drylot Emissions (per head):

The nitrous oxide emissions from the drylot are estimated using Equation B-4, where the drylot EF = 0.02.

$$= \frac{0.34 \text{ kg/day Nex}}{1{,}000 \text{ kg}} \times \frac{398 \text{ kg}}{\text{head}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{44 \ N_2O}{28 \ N} \times 0.02$$

$$= 1.55 \text{ kg/yr/head}$$

Pond without Settling Basin Emissions (per head):

To estimate emissions from a pond without solids separation, ERG estimated the addition of nitrogen to the pond from runoff. From the cost methodology report, ERG estimated that 2,242,228 kg/yr of solids are added to the pond from runoff from a Beef, Central, Large 2 operation. Assuming the runoff solids have the same characteristics as manure, ERG first estimated the amount of nitrogen added to the pond per head.

$$= \frac{2{,}242{,}228 \text{ kg runoff solids/yr}}{\text{model farm}} \times \frac{\text{model farm}}{25{,}897 \text{ head}} \times \frac{\text{year}}{365 \text{ days}} \times \frac{0.34 \text{ kg Nex/day}}{1{,}000 \text{ kg animal}} \times \frac{1{,}000 \text{ kg animal}}{63 \text{ kg manure/day}}$$

$$= 0.001 \text{ kg N/day/head}$$

[2]U.S. EPA. 2002a. *Cost Methodology Report for Animal Feeding Operations*. Washington, DC. December.

Next, the nitrous oxide emissions from the pond are estimated using Equation B-4, where the pond EF = 0.001.

$$= \frac{0.001 \text{ kg N/day}}{\text{head}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{44 \text{ N}_2\text{O}}{28 \text{ N}} \times 0.001$$

$$= 0.001 \text{ kg N}_2\text{O/yr/head}$$

<u>Pond with Settling Basin Emissions (per head)</u>:

To estimate emissions from a pond with solids separation, ERG estimated the addition of nitrogen to the pond from runoff following the solids separation step. From the cost methodology report, ERG estimated that 3,693,549 kg/yr of solids are added to the settling basin from runoff from a Beef, Central, Large 2 operation. Assuming the runoff solids have the same characteristics as manure and the settling basin has a 50 percent efficiency, ERG estimates the amount of nitrogen added to the pond per head and estimates the nitrous oxide emissions from the pond using Equation B-1, where the pond EF = 0.001.

$$= \frac{0.001 \text{ kg N/day}}{\text{head}} \times 0.50 \text{ efficiency} \times \frac{365 \text{ days}}{\text{year}} \times \frac{44 \text{ N}_2\text{O}}{28 \text{ N}} \times 0.001$$

$$= 0.0004 \text{ kg N}_2\text{O/yr/head}$$

<u>Weighted Sum of Component Emissions</u>

Using Equation B-2, ERG calculates the weighted average emissions per head for the model farm. For a Beef, Central, Large 2 operation with "low" requirements, it is assumed that all operations have a drylot and a waste storage pond in place. In addition, 60 percent of the operations have a solids separator prior to the runoff pond.

$$\text{Emission per Head}_{\text{model farm, low}}$$

$$= (\text{Drylot} \times 100\%) + (\text{Pond w/out settling} \times 40\%) + (\text{Pond w/settling} \times 60\%)$$

For our example calculation, the weighted emissions per head at a "low requirement" operation are:

$$= (1.55 \text{ kg N}_2\text{O/year} \times 100\%) + (0.001 \text{ kg N}_2\text{O/year} \times 40\%) + (0.0004 \text{ kg N}_2\text{O/year} \times 60\%)$$

$$= 1.55 \text{ kg N}_2\text{O/year}$$

The weighted emissions are calculated in a similar fashion for "medium" (1.55 kg N_2O/yr) and "high" (1.55 kg N_2O/yr) requirement facilities. The overall weighted emission per head is estimated as 25 percent of the "low" emission, 50 percent of the "medium" emission, and 25 percent of the "high" emission, or 1.55 kg N_2O/yr.

Total Model Farm Emissions for Baseline

The model farm emissions are calculated as the weighted emissions per head multiplied by the average number of head at the model farm.

$$\text{Emission per Model Farm, low} = \frac{\text{Weighted Emissions}}{\text{Head}} \text{ x } \frac{\text{Average Head}}{\text{Model Farm}}$$

For our example calculation, the model farm emissions are:

$$= \frac{1.55 \text{ kg } N_2O/\text{year}}{\text{head}} \times \frac{25{,}897 \text{ head}}{\text{Model Farm}}$$

$$= 40{,}196 \text{ kg } N_2O/\text{year}$$

Emissions for Regulatory Options 1-4 and 7

Under Options 1-4 and 7, it is assumed that all operations have a waste storage pond with settling basin in place. Therefore, when estimating total model farm emissions, the frequency factor for operations having a pond with settling basin is 100%, and the frequency factor for operations having a pond with no settling basin is 0%. The drylot portion of this calculation is the same as baseline.

Weighted Sum of Component Emissions

Using Equation B-2, ERG calculates the weighted average emissions per head for the model farm.

$$\text{Emission per Head}_{\text{model farm}} = (\text{Drylot} \times 100\%) + (\text{Pond w/out settling} \times 0\%) + (\text{Pond w/settling} \times 100\%)$$

For our example calculation, the weighted emissions per head are:

$$= (1.55 \text{ kg } N_2O/\text{year} \times 100\%) + (0.001 \text{ kg } N_2O/\text{year} \times 0\%) + (0.0004 \text{ kg } N_2O/\text{year} \times 100\%)$$

$$= 1.55 \text{ kg } N_2O/\text{year}$$

Total Model Farm Emissions for Options 1-4, 7

The model farm emissions are calculated as the weighted emissions per head multiplied by the average number of head at the model farm.

$$\text{Emission per Model Farm} = \frac{\text{Weighted Emissions}}{\text{Head}} \times \frac{\text{Average Head}}{\text{Model Farm}}$$

For our example calculation, the model farm emissions are:

$$= \frac{1.55 \text{ kg } N_2O\text{/year}}{\text{head}} \times \frac{25{,}897 \text{ head}}{\text{Model Farm}}$$

$$= 40{,}189 \text{ kg } N_2O\text{/year}$$

Emissions for Regulatory Option 5A

Option 5A assumes that all solids removed by the settling basin and all solids scraped from the drylot are composted. The drylot and pond with basin portions of this calculation are the same as those for regulatory options 1-4 and 7.

Compost Emissions (per head):

To estimate emissions from a compost pile, ERG estimated the addition of nitrogen to the pile using data from literature. As discussed in Section 2.2 of this report, ERG estimates that 25.71 pounds of nitrogen per ton of manure excreted is present in the compost pile at a Beef, Central, Large 2 operation. ERG estimates the amount of nitrogen added to the compost pile per head and estimates the nitrous oxide emissions from the pond using Equation B-4, where the compost EF = 0.02.

$$= \frac{44{,}200 \text{ tons manure compost/yr}}{\text{model farm}} \times \frac{25.71 \text{ lb N to compost}}{\text{ton manure}} \times \frac{\text{kg}}{2.20462 \text{ lb}} \times \frac{\text{year}}{365 \text{ days}} \times \frac{1}{25{,}897 \text{ head}}$$

$$= 0.055 \text{ kg N to compost/day/head}$$

$$= \frac{0.055 \text{ kg N to compost/day}}{\text{head}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{44 \ N_2O}{28 \ N} \times 0.02$$

$$= 0.63 \text{ kg } N_2O\text{/year/head}$$

Weighted Sum of Component Emissions

Using Equation B-2, ERG calculates the weighted average emissions per head for the model farm.

$$\text{Emission per Head}_{\text{model farm}} = (\text{Drylot} \times 100\%) + (\text{Compost} \times 100\%) + (\text{Pond w/settling} \times 100\%)$$

For our example calculation, the weighted emissions per head are:

$$= (1.55 \text{ kg } N_2O/\text{year} \times 100\%) + (0.63 \text{ kg } N_2O/\text{year} \times 100\%) + (0.0004 \text{ kg } N_2O/\text{year} \times 100\%)$$

$$= 2.18 \text{ kg } N_2O/\text{year}$$

Total Model Farm Emissions for Option 5A

The model farm emissions are calculated as the weighted emissions per head multiplied by the average number of head at the model farm.

$$\text{Emission per Model Farm} = \frac{\text{Weighted Emissions}}{\text{Head}} \times \frac{\text{Average Head}}{\text{Model Farm}}$$

For our example calculation, the model farm emissions are:

$$= \frac{2.18 \text{ kg } N_2O/\text{year}}{\text{head}} \text{ x } \frac{25{,}897 \text{ head}}{\text{Model Farm}}$$

$$= 56{,}400 \text{ kg } N_2O/\text{year}$$

Industry-level results for each threshold considered are simply calculated as the model farm results multiplied by the number of facilities (as defined in Section 1).

Appendix C

Detailed Calculations for Air Emissions from Animal Confinement and Manure Management Systems - Energy Recovery Systems

Introduction

Appendix C presents an example calculation for emissions of nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon monoxide (CO),from energy recovery systems used at animal feeding operations. This appendix supplements the text presented in Section 2.3 of this report.

Assumptions Used in Calculations

ERG made the following assumptions to calculate emissions from energy recovery systems:

- Under Option 6, the biogas is sent to an engine for recovery. It is assumed that 70 percent of the biogas is methane[1,2] and 30 percent of the biogas is carbon dioxide;

- The methane is used in an engine to generate electricity, with a 100 percent rate of conversion of methane to electricity; and

- Total nitrogen into the digester or covered lagoon is also discharged from the digester or covered lagoon into the holding pond or secondary lagoon (that is, ammonia is not volatilized into the gas collection system and sent to the energy recovery system).

For dairies, emissions for flush and hose/scrape dairies are calculated separately. Then, the two types of operations are combined into a single model farm in Table C-3 using farm-type frequency factors (presented in Appendix A). These factors provide the percentage of operations in that model farm group that are flush operations verses hose operations, and the emissions are weighted according to these factors. For further description of the farm-type factors, see the Cost Methodology Report for Animal Feeding Operations.[3]

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[1]Jones, D., J. Nye, and A. Dale. 2000. *Methane Generation From Livestock Waste*. <http://persephone.agcom.purdue.edu/~agcom/Pubs/AE/AE-105.html>. (November)

[2]Schultz, T. and C. Collar. 1993. Dairying and Air Emissions. In: *Dairy Manure Management Series*. University of California.

[3]EPA. 2002a. *Cost Methodology Report for Animal Feeding Operations*. Washington, DC. December 2002.

Biogas Calculation Example:

Using Equation C-1, a total volume of biogas is calculated from the methane mass values by converting to a volumetric flow basis using the ideal gas law at standard temperature and pressure.

<u>Model Farm Data</u> (from Section 1):

Farm Type:	Farrow-to-finish swine
Size:	Large 2 (17,118 head)
Region:	Mid-Atlantic
Methane Generation:	451,930 kg/yr

$$PV = nRT \tag{C-1}$$

where:

P = pressure = 1.01325×10^5 Pa
R = gas law constant = 8.314 (m^3 x Pa)/ (mol x K)
T = temperature = 293 K
n = moles of gas = (m_{CH4}/MW_{CH4}) x 1000
m_{CH4} = methane mass generation value from OW calculation (kg/yr)
MW_{CH4} = methane molecular weight = 16 g/mol

For the farm listed, the methane volume (V_{CH4}) is calculated as follows using Equation C-1:

$$1.01325x10^5 \times V_{CH4} = \left(\frac{451,930}{16}\right) \times 1,000 \times 8.314 \times 293$$

$$V_{CH4} = 679,066 \text{ m}^3/\text{yr}$$

Total volume of biogas (V_{bio}) generated and collected is calculated using Equation C-2.

$$V_{CH4} = 0.70 \text{ x } V_{bio} \tag{C-2}$$

Therefore,

$$V_{bio} = 679,066 \div 0.7 = 970,094 \text{ m}^3/\text{yr}$$

SO_2 Calculation Example:

From data presented in available literature, it is assumed that 0.36 percent by volume of the biogas was hydrogen sulfide (H_2S). The H_2S volume (V_{H2S}) is calculated using Equation C-3:

$$V_{H2S} = V_{bio} \text{ x } 0.0036 \tag{C-3}$$

Therefore,

$$V_{H2S} = 679{,}066 \text{ x } 0.0036 = 3{,}492.3 \text{ m}^3/\text{yr}$$

Based on AP-42 data, all the H_2S in the biogas will be completely oxidized into SO_2 in either a flare or a gas turbine. Equation C-4 gives the calculation used to estimate SO_2.

$$m_{SO2} = \frac{P \times V_{H2S} \times MW_{H2S}}{R \times T \times 1000} \times \frac{MW_{SO2}}{MW_{H2S}} \tag{C-4}$$

where:

m_{SO2} = mass of SO_2 emitted (kg/yr)
MW_{H2S} = molecular weight of H_2S = 34 g/mol
MW_{SO2} = molecular weight of SO_2 = 64 g/mol.

Annual SO_2 emissions are therefore calculated as:

$$m_{SO2} = \frac{1.01325\text{x}10^5 \times 3492.3 \times 34}{8.314 \times 293 \times 1000} \times \frac{64}{34} = 9{,}306$$

CO Calculation Example:

Emission factors for landfill gas combustion are given in AP-42. Since CAFO biogas emission factors are unavailable and that the CAFO biogas is mostly composed of methane, the landfill gas factors are used in calculating CO and thermal NOx generation. Equation C-5 is used to calculate CO emissions.

$$m_{CO} = V_{CH4} \times C_{vol} \times \frac{EF}{1\text{x}10^6} \times \frac{1}{C_{mass}} \tag{C-5}$$

where:

m_{CO} = mass of CO emitted (kg/yr)
C_{vol} = volume conversion factor = 35.314 ft^3/m^3
EF = emission factor = 750 lbs CO / million ft^3 CH_4 combusted (flaring)
C_{mass} = mass conversion factor = 2.2 lb/kg.

Therefore, for the flare case,

$$m_{co} = 679{,}066 \text{ x } 35.314 \text{ x } 750 \div (1{,}000{,}000 \text{ x } 2.2) = 8{,}175 \text{ kg/yr}$$

Thermal NOx Calculation:

Thermal NOx is also calculated using AP-42 combustion emission factors. Equation C-5 is also used to calculate thermal NOx, with the following modifications:

- Replace m_{CO} with m_{tNOx} = mass of thermal NOx emitted (kg/yr); and
- Emission factors for NOx are used instead of CO (for flare, EF = 40 lbs NOx/ million ft^3 CH_4 combusted).

Therefore, the resulting calculation is:

$$m_{tNOx} = 679{,}066 \text{ x } 35.314 \text{ x } 40 \div (1{,}000{,}000 \text{ x } 2.2) = 436 \text{ kg/yr}$$

Fuel NOx Calculation:

This is calculated in a manner very similar to that used to estimate SO_2 emissions. Equation C-3 is used to calculate the volumetric flow rate of NH_3 (V_{NH3}) in the biogas. A literature review revealed that biogas from animal operations contains 1.67 percent NH_3 by volume. Therefore, substituting into C-3 results in the following:

$$V_{NH3} = V_{bio} \text{ x } 0.0167$$

$$= 970{,}094 \text{ x } 0.0167 = 16{,}200 \text{ m}^3\text{/yr}$$

Substituting into Equation C-4, accounting for different molecular weights and assuming that only 30 percent of the NH3 is converted to NOx (from literature search), Equation C-6 is obtained for estimating annual fuel NOx emissions.

$$m_{fNOx} = \frac{P \times V_{NH3} \times MW_{NH3}}{R \times T \times 1000} \times \frac{MW_{NOx}}{MW_{NH3}} \times 0.3 \qquad \text{(C-6)}$$

where:

m_{fNOx} = annual fuel NOx emissions (kg/yr)
MW_{NH3} = molecular weight of NH_3 = 17 g/mol
MW_{NOx} = molecular weight of NOx (as N_2O) = 44 g/mol

The resultant emission calculation is:

$$m_{fNOx} = \frac{1.01325x10^{5} \times 16200 \times 17}{8.314 \times 293 \times 1000} \times \frac{44}{17} \times 0.3 = 8{,}895 \text{ kg / yr}$$

Total NOx:

The total annual NOx emission (m_{NOx}) is simply the sum of thermal and fuel NOx emissions. In this example, total NOx is:

$$m_{NOx} = m_{tNOx} + m_{fNOx}$$

$$= 436 + 8{,}895 = 9{,}331 \text{ kg/yr}$$

Results

The volume of biogas and the engine emissions generated at each model farm are presented in section 2.3 of the text in Tables 2.3-2 through 2.3-5.

Appendix D

Detailed Calculations for Air Emissions - Land Application Activities

Introduction

Appendix D presents example calculations for ammonia and nitrous oxide emissions from the land application of solid and liquid waste, both on site and off site. These calculations follow the methodology presented in Section 3 of this report. All ammonia emissions are reported in units of tons per year. All nitrous oxide emissions are reported in units of Tg-CO_2 equivalent, which normalizes the reported emissions of greenhouse gases to carbon dioxide. The greenhouse warming potential of nitrous oxide is 310 times that of carbon dioxide.

ERG calculates the annual industry level pounds of liquid and solid nitrogen being applied on and off site, at baseline and under the different regulatory options, using nitrogen data from the cost model.[1] The cost model multiplies the amount of nitrogen going to land application for each model farm by the appropriate number of facilities (broken out by size group; region; category; and high, medium, and low requirement operations. Under Option 1 the cost model assumes that all facilities apply their nitrogen agronomically using a nitrogen-based application rate. Under Options 2-7, the cost model distinguishes between facilities that agronomically apply their nitrogen using a nitrogen-based application rate and those using a phosphorous based-application rate. At baseline, the cost model uses a frequency factor to account for both Category 2 facilities that over apply their nitrogen and Category 2 facilities that apply their nitrogen agronomically using a nitrogen-based application rate.

Example Calculation:

ERG calculates the total liquid and solid nitrogen going to on-site and off-site land application for each animal type by summing the nitrogen from the cost model for each size group; region; category; and high, medium, and low requirement operations. These totals are presented in Table 3.1-2. EPA then calculates the total ammonia emissions that occur both on site and off site for each animal type using the data in Table 3.1-2, Equations D-1 and D-2, and the animal-specific ammonia volatilization rates presented in Table 3.2-1.

$$NH_3\ Emissions_{on-site} = (Solid\ N_{on-site} \times \%\ Volatilization_{Solid}) + (Liquid\ N_{on-site} \times \%\ Volatilization_{Liquid}) \quad (D\text{-}1)$$

$$NH_3\ Emissions_{off-site} = (Solid\ N_{off-site} \times \%\ Volatilization_{Solid}) + (Liquid\ N_{off-site} \times \%\ Volatilization_{Liquid}) \quad (D\text{-}2)$$

ERG then calculates the total nitrous oxide emissions that occur both on site and off site for each animal type using Equations D-3 and D-4 and the animal-specific ammonia volatilization rates presented in Table 3.2-1. This methodology assumes that one percent of the nitrogen that volatilizes as ammonia eventually becomes nitrous oxide, and 1.25 percent of the nitrogen that is land applied but does not volatilize to ammonia will be emitted as nitrous oxide. Equation D-5 is

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[1] U.S. EPA. 2002a. *Cost Methodology Report for Animal Feeding Operations*. Washington, DC. December 2002.

used to convert the units of nitrous oxide emissions from pounds per year to Tg-CO_2 equivalent per year.

$$\begin{aligned}
&N_2O\ \text{Emissions}_{\text{on site}} = \\
&[(\%\ \text{Volatilization}_{\text{Solid}} \times \text{Solid}_{\text{on site}}) + (\%\ \text{Volatilization}_{\text{Liquid}} \times \text{Liquid}_{\text{on site}})] \times 0.01 + \\
&[(1 - \%\ \text{Volatilization}_{\text{Solid}}) \times \text{Solid}_{\text{on site}}] + [(1 - \%\ \text{Volatilization}_{\text{Liquid}}) \times \text{Liquid}_{\text{on site}}] \times 0.0125 \\
&\times \frac{44\ N_2O}{28\ N_2}
\end{aligned} \qquad \text{(D-3)}$$

$$\begin{aligned}
&N_2O\ \text{Emissions}_{\text{off site}} = \\
&[(\%\ \text{Volatilization}_{\text{Solid}} \times \text{Solid}_{\text{off site}}) + (\%\ \text{Volatilization}_{\text{Liquid}} \times \text{Liquid}_{\text{off site}})] \times 0.01 + \\
&[(1 - \%\ \text{Volatilization}_{\text{Solid}}) \times \text{Solid}_{\text{off site}}] + [(1 - \%\ \text{Volatilization}_{\text{Liquid}}) \times \text{Liquid}_{\text{off site}}] \times 0.0125 \\
&\times \frac{44\ N_2O}{28\ N_2}
\end{aligned} \qquad \text{(D-4)}$$

$$N_2O\ \text{Emissions (Tg}-CO_2\ \text{Equivalent/yr)} = N_2O\ \text{Emissions (lb/yr)} \div 2.2\ \text{lb/kg} \div 10^9\ \text{kg/Tg} \times 310 \qquad \text{(D-5)}$$

For example, the calculations of annual emissions of ammonia and nitrous oxide from beef CAFOs are shown below.

Baseline Emissions

At baseline it is assumed that some Category 2 facilities over apply their waste on site and some Category 2 facilities apply their waste agronomically using a nitrogen-based application rate. Category 1 facilities apply all of their waste on site, and Category 3 facilities apply all of their waste off site.

Ammonia

The on-site and off-site ammonia emissions from land application are estimated using Equations D-1 and D-2, where the pounds of nitrogen applied are presented in Table 3.1-2 (119,360,643 pounds solid nitrogen and 35,053,523 pounds liquid nitrogen are applied on site; 261,574,770 pounds solid nitrogen and 18,753,422 pounds liquid nitrogen are applied off site) and the percent nitrogen volatilization rates are presented in Table 3.2-1 (solid nitrogen volatilization = 17 percent and liquid nitrogen volatilization = 20 percent). For example, for beef CAFOs, the on-site ammonia emissions are:

$$= [(119{,}360{,}643 \text{ lb/yr} \times 0.17) + (35{,}053{,}523 \text{ lb/yr} \times 0.20)] \div 2{,}000 \text{ lb/ton}$$

$$= 13{,}651 \text{ tons/yr}$$

The off-site ammonia emissions are:

$$= (261{,}574{,}770 \text{ lb/yr} \times 0.17) + (18{,}753{,}422 \text{ lb/yr} \times 0.20) \div 2{,}000 \text{ lb/ton}$$

$$= 24{,}109 \text{ tons/yr}$$

Nitrous Oxide

The on site and off site nitrous oxide emissions from land application are estimated using Equations D-3 through D-5, where the pounds of nitrogen applied are presented in Table 3.1-2 (119,360,643 pounds solid nitrogen and 35,053,523 pounds liquid nitrogen are applied on site; 261,574,770 pounds solid nitrogen and 18,753,422 pounds liquid nitrogen are applied off site) and the percent nitrogen volatilization rates are presented in Table 3.2-1 (solid nitrogen volatilization = 17 percent and liquid nitrogen volatilization = 20 percent). For example, for the beef industry, the on-site nitrous oxide emissions are:

$$= [(0.17 \times 119{,}360{,}643 \text{ lb/yr} + 0.20 \times 35{,}053{,}523 \text{ lb/yr}) \times 0.01 +$$

$$[(1 - 0.17) \times 119{,}360{,}643 \text{ lb/yr} + (1 - 0.20) \times 35{,}053{,}523 \text{ lb/yr}] \times 0.0125] \times \frac{44}{28}$$

$$= 2{,}925{,}877 \text{ lb/yr}$$

The off-site nitrous oxide emissions are:

$$= [(0.17 \times 261{,}574{,}770 \text{ lb/yr} + 0.20 \times 18{,}753{,}422 \text{ lb/yr}) \times 0.01 +$$

$$[(1 - 0.17) \times 261{,}574{,}770 \text{ lb/yr} + (1 - 0.20) \times 18{,}753{,}422 \text{ lb/yr}] \times 0.0125] \times \frac{44}{28}$$

$$= 5{,}317{,}017 \text{ lb/yr}$$

Emissions Under Regulatory Options 1 through 7

The calculation of ammonia and nitrous oxide emissions under the different regulatory options use the same methodology as described for baseline, using Equations D1 through D5, the data inputs for the liquid and solid pounds of nitrogen applied on site and off site under the different regulatory options presented in Table 3.1-2, and the animal-specific ammonia volatilization rates presented in Table 3.2-1. The pounds of nitrogen going to land application differs by regulatory option, as described below.

Emissions for Regulatory Option 1

Under Option 1 all facilities apply their nitrogen agronomically using a nitrogen-based application rate. Because no Category 2 facilities over apply their waste on site (all facilities use a nitrogen-based application rate), the distribution of pounds of nitrogen being applied on site and off site (and therefore, the distribution of emissions that occur on site and off site) differ from baseline.

Emissions for Regulatory Options 2-4, 6, and 7

Under Options 2 through 4, 6, and 7 all facilities apply their nitrogen agronomically using a nitrogen-based application rate or a phosphorus-based application rate. Because no Category 2 facilities over apply their waste on site (all facilities use either a nitrogen-based application rate or a phosphorus-based application rate), the distribution of pounds of nitrogen being applied on site and off site (and therefore, the distribution of emissions that occur on site and off site) differ from baseline and Option 1.

Emissions for Regulatory Option 5A

Under Option 5A all facilities apply their nitrogen agronomically using a nitrogen-based application rate or a phosphorus-based application rate (the same as Options 2 through 4, 6, and 7). Because the solid waste is composted before land application under Option 5A, the nitrogen going to land application is in a more stable form, and the percent of solid nitrogen expected to volatilize to ammonia decreases from 17 percent to 2 percent.

Appendix E

Detailed Calculations for Emissions from Vehicles - Off-Site Transportation

Introduction

Appendix E presents example calculations for volatile organic compounds, nitrogen oxides, carbon monoxide and particulate matter emissions from the transportation of solid and liquid waste off site. These calculations follow the methodology presented in Section 4 of this report. All criteria air emissions are presented in units of tons per year.

ERG calculates the annual industry level pounds of liquid and solid manure being transported off site under the different regulatory options, using manure data from the cost model.[1] As described in Section 4 of the report, there are four potential methods of transporting the manure off site, and the cost model is designed to select the most cost effective method for each operation. The output from the cost model includes the method of transport selected for each operation and the industry level miles traveled while transporting the liquid waste and solid waste off site (broken out by size group; region; high, medium and low requirement operations; and Category 1, Category 2 and Category 3 operations).

Example Calculation:

ERG calculates the total incremental miles traveled above baseline transporting solid manure and liquid manure off site for each animal type under the regulatory options by summing the mileages from the cost model for each size group; each region; high, medium, and low requirement operations; and Category 1, Category 2, and Category 3 operations. These data inputs are presented in Table 4.1-2. ERG then calculates the total incremental volatile organic compounds, nitrogen oxides, carbon monoxide, and particulate matter emissions that occur above baseline while transporting solid and liquid manure off site for each animal type under the different regulatory options. Equation E-1 is the general equation used to estimate the criteria air emissions, using the total additional miles traveled above baseline data presented in Table 4.1-2 and the emission factors for diesel vehicles presented in Table 4.1-1.

$$\text{Total Pollutant Emitted (tons)} = \frac{(\text{Miles}_{\text{Solid}} \times \text{Pollutant EF}_{\text{Solid}}\ (\text{grams/mi})) + (\text{Miles}_{\text{Liquid}} \times \text{Pollutant EF}_{\text{Liquid}}\ (\text{grams/mi}))}{454\ \text{grams/pound} \times 2000\ \text{pounds/ton}} \qquad \text{(E-1)}$$

The following example presents the calculations of the additional annual criteria air emissions from baseline to Option 1 for the dairy CAFOs.

Emissions Above Baseline - Option 1

The increase in criteria air emissions above baseline are calculated using Equation E-1, the additional miles traveled from baseline calculated for Option 1 presented in Table 4.1-2 of the NWQI report (959,068 miles hauling solid manure; 27,757,298 miles hauling liquid manure), and the transportation emission factors presented in Table 4.1-1. The resulting

[1] U.S. EPA. 2002a. *Cost Methodology Report for Animal Feeding Operations*. Washington, DC. December.

transportation emissions are presented in Section 4 of the NWQI report, in Tables 4.1-3 through 4.1-6.

Volatile Organic Carbon Emissions (tons/yr)

$$\text{Total VOCs Emitted (tons/yr)}$$

$$= \frac{(959{,}068 \text{ solid miles} \times 1.08 \text{ grams/mile}) + (27{,}757{,}298 \text{ liquid miles} \times 1.35 \text{ grams/mile})}{(454 \text{ grams/pound}) \times (2000 \text{ pounds/ton})}$$

$$= 45.5 \text{ tons/yr}$$

Nitrogen Oxides Emissions (tons/yr)

$$\text{Total Nitrogen Oxides Emitted (tons/yr)}$$

$$= \frac{(959{,}068 \text{ solid miles} \times 23.67 \text{ grams/mile}) + (27{,}757{,}298 \text{ liquid miles} \times 27.6 \text{ grams/mile})}{(454 \text{ grams/pound}) \times (2000 \text{ pounds/ton})}$$

$$= 868.7 \text{ tons/yr}$$

Carbon Monoxide Emissions (tons/yr)

$$\text{Total Carbon Monoxide Emitted (tons/yr)}$$

$$= \frac{(959{,}068 \text{ solid miles} \times 5.87 \text{ grams/mile}) + (27{,}757{,}298 \text{ liquid miles} \times 7.83 \text{ grams/mile})}{(454 \text{ grams/pound}) \times (2000 \text{ pounds/ton})}$$

$$= 245.6 \text{ tons/yr}$$

Particulate Matter Emissions (tons/yr)

$$\text{Total Particulate Matter Emitted (tons/yr)}$$

$$= \frac{(959{,}068 \text{ solid miles} \times 0.857 \text{ grams/mile}) + (27{,}757{,}298 \text{ liquid miles} \times 0.857 \text{ grams/mile})}{(454 \text{ grams/pound}) \times (2000 \text{ pounds/ton})}$$

$$= 27.1 \text{ tons/yr}$$

Emissions Under Options 1-7

At baseline it is assumed that some Category 2 facilities over apply their waste on site and some Category 2 facilities apply their waste agronomically using a nitrogen-based application rate. However, under the different regulatory options it is assumed that all facilities (including Category 2 facilities) apply their waste agronomically using either a nitrogen-based or phosphorus-based application rate. Therefore, the Category 2 facilities that over applied their waste at baseline now apply at an agronomic rate, and have more manure to transport off site.

The transportation of this excess manure off site results in more miles being traveled and more criteria air emissions.

Although Category 3 facilities transport all of their manure off site at baseline, a regulation that requires phosphorous-based application may cause facilities to transport their manure a further distance; therefore, there may also be an increase in the amount of criteria air pollutants generated by these operations.

The criteria air emissions generated under each regulatory option are directly dependent on the miles traveled to transport the manure off site, and the number of miles traveled are directly dependent on the quantity of manure that needs to be transported off site There is an increase in emissions from baseline to Option 1, as shown in the example above, because Category 2 facilities no longer over apply their manure, resulting in a reduced on-site application rate and therefore more manure transported off site. There is an even greater increase in emissions from baseline to Options 2-4, 7 because some facilities apply their manure using a phosphorous-based application rate, resulting in an even more reduced on-site application rate and therefore more manure transported off site. The increase in emissions from baseline to Option 5A is not quite as great as it is for Options 2-4, 7 because the volume of manure going to land application is slightly reduced during composting. The increase in emissions from baseline to Option 6 is relatively small because the manure is first sent to an anaerobic digester.

Appendix F

Detailed Calculations for Emissions from Vehicles Used for Composting

Introduction

Appendix F presents an example of the calculations used to estimate the criteria air emissions (VOCs, NOx, PM, and CO) from vehicles used for composting. These calculations follow the methodology presented in Section 4.2 of this report.

Data Inputs

Tables 4.1-1 and 4.2-1 contain the data inputs used to calculate the criteria air emissions from vehicles used for composting. Table 4.1-1 presents emission factors for fleet vehicles from MOBILE6[1] and AP-42.[2] Table 4.2-1 presents the number of miles traveled during on-site composting calculated by the cost model.[3]

Assumptions

Criteria air emissions resulting from composting activities are calculated for Option 5A beef, dairy, and heifer CAFOs. ERG assumes that farms do not compost in the baseline scenario; therefore, all emissions listed in Table 4.2-2 represent post-regulatory emissions. Emissions are calculated for the composting of all solids generated on site. It is assumed that the tractor used to turn the compost pile is the only source of criteria air emissions.

Section 4.2 of this report summarizes the methodology used to estimate the annual running time of the tractor used to turn the manure. The annual criteria air emissions from composting operations are determined using the data inputs from Tables 4.1-1 and 4.2-1 and Equation F-1.

$$\text{Total Pollutant Emitted (tons/yr)} = \frac{\text{Total Miles (miles/yr)} \times \text{Pollutant Emision Factor (grams/miles)}}{\text{(454 grams/pound)} \times \text{(2000 pounds/ton)}} \qquad \text{[F-1]}$$

The following example calculations use the industry miles traveled data calculated for beef CAFOs (91,172 miles), presented in Table 4.2-1. The miles traveled data for beef, heifer, and dairy CAFOs are presented in this table.

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[1] U.S. EPA. 2002. Mobile 6 Vehicle Emission Modeling Software. http://www.epa.gov/otaq/m6.htm#m60.

[2] U.S. EPA. 1985. *Compilation of Air Pollution Emission Factors*, 4th ed. AP-42. Research Triangle Park, North Carolina.

[3] U.S. EPA. 2002a. *Cost Methodology Report for Animal Feeding Operations*. Washington, DC. December 2002.

Volatile Organic Carbon Emissions (tons/yr)

$$\text{Total VOCs Emitted (tons/yr)} = \frac{91{,}172 \text{ (miles)} \times 1.08 \text{ (grams/mile)}}{(454 \text{ grams/pound}) \times (2000 \text{ pounds/ton})} = 0.108 \text{ (tons/yr)}$$

Nitrogen Oxides Emissions (tons/yr)

$$\text{Total Nitrogen Oxides Emitted (tons/yr)} = \frac{91{,}172 \text{ (solid miles)} \times 23.67 \text{ (grams/mile)}}{(454 \text{ grams/pound}) \times (2000 \text{ pounds/ton})} = 2.377 \text{ (tons/yr)}$$

Carbon Monoxide Emissions (tons/yr)

$$\text{Total Carbon Monoxide Emitted (tons/yr)} = \frac{91{,}172 \text{ (solid miles)} \times 5.87 \text{ (grams/mile)}}{(454 \text{ grams/pound}) \times (2000 \text{ pounds/ton})} = 0.589 \text{ (tons/yr)}$$

Particulate Matter Emissions (tons/yr)

$$\text{Total Particulate Matter Emitted (tons/yr)} = \frac{91{,}172 \text{ (solid miles)} \times 0.857 \text{ (grams/mile)}}{(454 \text{ grams/pound}) \times (2000 \text{ pounds/ton})} = 0.086 \text{ (tons/yr)}$$

Appendix G

Detailed Calculations for Energy Impacts - Land Application

Introduction

Appendix G presents the derivation of the equations used to estimate energy impacts from land application, approximated by the application of liquid waste using center pivot or traveling gun irrigation. This appendix also includes a sample calculation, which follows the methodology presented in Section 5.1 of this report. All operations are expected to conduct land application/irrigation under the regulatory options. The greatest increase in electricity use is expected for the Medium beef, heifer, and dairy CAFOs; no additional energy use is expected for veal, swine, or poultry CAFOs under any regulatory option. The irrigated acres and frequency factors for Category 1 and 2 facilities are determined from the cost model used to estimate compliance costs for these operations.[1]

Center Pivot Irrigation

Farms with more than 30 acres available for liquid land application are assumed to use center pivot irrigation systems. To determine the energy required to operate the system, vendor data presented in Section 5.1 relating the irrigated acres to electrical energy and diesel pump energy are plotted on a linear curve (Figure G-1) that is used to calculate the required horsepower of the center pivot for each model farm.[2,3,4] The equation for the curve has a regression coefficient of 0.973.

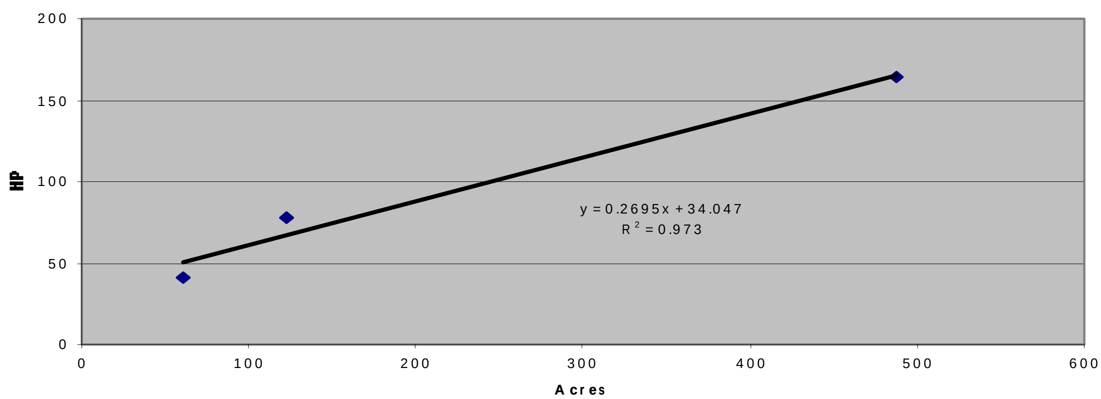

Figure G-1. Required Horsepower for Center Pivot Irrigation

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[1]U.S. EPA. 2002a. *Cost Methodology Report for Animal Feeding Operations.* Washington, DC. December 2002.

[2]Zimmatic. 2000. Zimmatic System Configuration Economic Comparison Guide. <www.Zimmatic.com>. January 6.

[3]Kifco. 2001. Kifco "B" Series Performance Guide <www.kifco.com>. November 2001.

[4]Caprari. 2002. Caprari Pumps Performance Data <www.caprari.com>. May 2002.

The annual model farm estimates for energy use of center pivot irrigation systems are calculated using Figure G-1 and Equations G-1 and G-2. It is assumed that the irrigation system is operated 1,000 hours per year. Therefore:

$$\text{Required Horsepower (HP)} = (0.2695 \times \text{Irrigated Acres}) + 34.047 \tag{G-1}$$

$$\begin{aligned} &\text{Energy Use per Model Farm (kW-hr/yr)} \\ &= \text{Required Horsepower} \times 1{,}000 \text{ hours/yr} \times 0.7457 \text{ kW-hr/HP-hr} \times \text{FrequencyFactor} \end{aligned} \tag{G-2}$$

For example, the annual model farm estimates from a Beef, Pacific, Medium1 CAFO for Option 1, Category 1 are:

$$\begin{aligned} &\text{Required Horsepower (HP)} \\ &= (0.2695 \times 97 \text{ acres}) + 34.047 \\ &= 60.189 \end{aligned}$$

$$\begin{aligned} &\text{Energy Use per Model Farm (kW-hr/yr)} \\ &= 60.189 \times 1{,}000 \text{ hours/yr} \times 0.7457 \text{ kW-hr/HP-hr} \times 50\% \\ &= 22{,}441 \text{ kW-hr/yr} \end{aligned}$$

Industry-level results are simply calculated as the model farm results multiplied by the number of facilities (as defined in Section 6).

Traveling Gun Irrigation

Farms with less than 30 acres available for liquid land application are assumed to use traveling gun irrigation systems. To determine the energy required to operate the system, vendor data presented in Section 5.1 relating the irrigated acres to flow rate and horsepower are plotted on linear curves (Figures G-2 and G-3) that are used to calculate the required horsepower of the traveling gun for each model farm. The equation for flow rate has a regression coefficient of 0.9987, while the equation for horsepower has a regression coefficient of 0.9851.

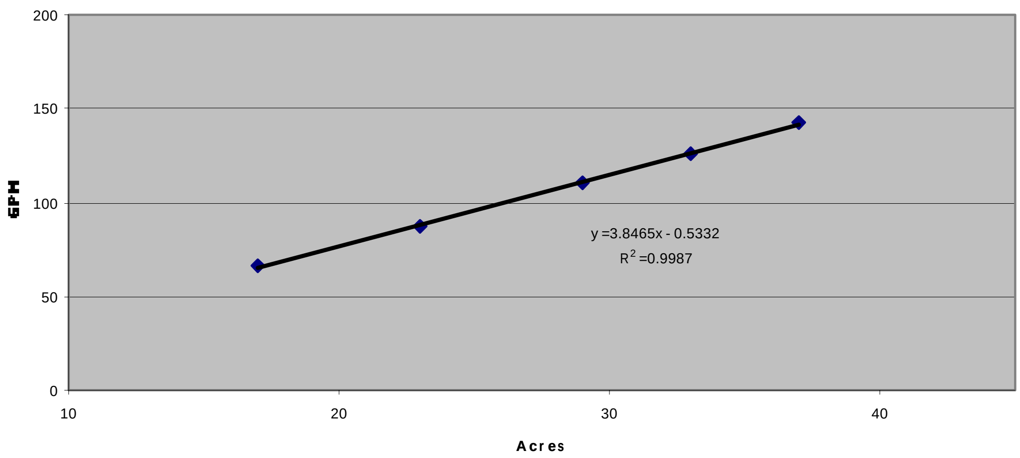


Figure G-2. Required Flow Rate for Model Farms–Traveling Gun Irrigation

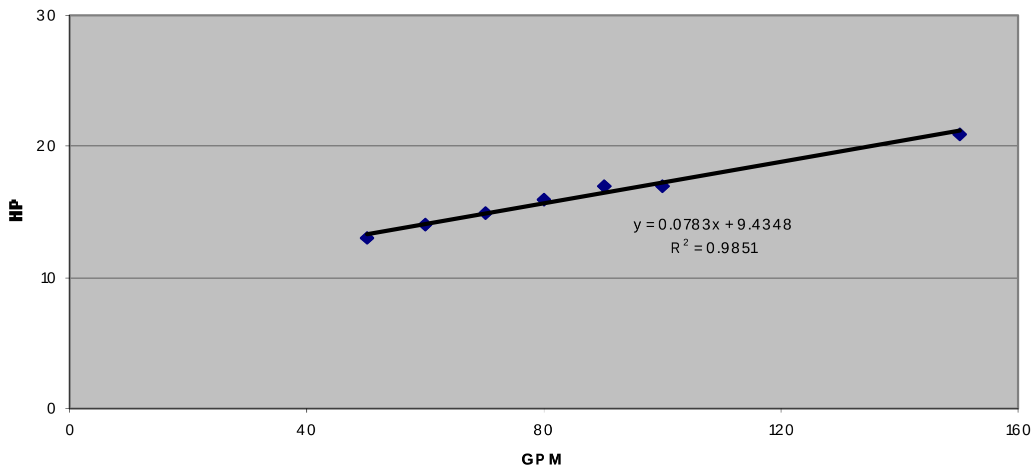


Figure G-3. Required Horsepower for Model Farms–Traveling Gun Irrigation

The annual model farm estimates for energy use of traveling gun irrigation systems are calculated using Figures G-2 and G-3 and Equations G-3 and G-4. It is assumed that the irrigation system is operated 1,000 hours per year. Therefore:

$$\text{Required Flowrate (gal/min)} = (3.8465 \times \text{Irrigated Acres}) - 0.5332 \qquad \text{(G-3)}$$

$$\text{Required Horsepower (HP)} = (0.0783 \times \text{Flow Rate}) + 9.4348 \qquad \text{(G-4)}$$

For example, the required flow rate and horsepower for a Beef, Pacific, Medium1 CAFO for Option 1, Category 1 is:

$$\text{Required Flowrate (gpm)} = (3.8465 \times 8.12 \text{ acres}) - 0.5332 = 30.61$$

$$\text{Horsepower (kW-hr/yr)} = (0.0783 \times 30.61 \text{ gpm}) + 9.4348 = 11.83$$

Industry-level results are simply calculated as the model farm results multiplied by the number of facilities (as defined in Section 6).

Appendix H

Detailed Calculations for Energy Impacts - Anaerobic Digesters with Methane Recovery

Introduction

Appendix H presents example calculations used to generate model farm energy impacts from anaerobic digesters with methane recovery for Large dairy and swine CAFOs. Estimates are obtained using the methodology presented in Section 5.3 of this report and apply only to Option 6.

The parameters specific to each swine model farm used in the *FarmWare* model are presented in Tables H-1 and H-2 of this appendix; dairy model farm parameters are presented in the cost report.[1] All other *FarmWare* inputs (including items such as temperature and rainfall data) resort to the program defaults.

The baseline electricity is estimated by the *FarmWare* model as the total electricity required to operate the dairy or swine operation prior to the installation of the anaerobic digester. The *FarmWare* model also estimates the total electricity required to operate the dairy or swine operation after the installation of the anaerobic digester (Option 6). ERG estimates the energy savings under Option 6 by calculating the difference between the electrical requirements before and after the installation of the digester.

Example Energy Usage Calculation

This appendix presents an example calculation of energy usage under Option 6 for a Large dairy operation. The *FarmWare* assessment for a Large flush dairy in Tulare, California is presented in Figure H-1 of this appendix. The assessment contains the details of the model farm, including the parameters of the selected methane recovery system, and the energy and financial performance of the system. Figure H-1 presents the required peak kilowatts required for the model farm both before and after the installation of the anaerobic digester. Equation H-1 is used to calculate the farm energy capacity, where the numbers of hours operated annually is 8,760, as shown in Figure H-1.

$$\text{Annual Farm Energy (kW-hr/year)} = \text{Peak Demand (kW)} \times 8{,}760 \text{ (hr/year)} \qquad \text{(H-1)}$$

The *FarmWare* model estimates the required peak kilowatts at baseline and after the installation of the anaerobic digester. Using Equation H-1 and the farm peak demands presented in Figure H-1, the electrical requirements at baseline and under Option 6 are calculated.

$$\text{Annual Farm Energy, Baseline (kW-hr/year)} = 159.4 \text{ (kW)} \times 8{,}760 \text{ (hr/year)} = 1{,}396{,}344 \text{ kW-hr/year}$$

$$\text{Annual Farm Energy, Option 6 (kW-hr/year)} = 103.7 \text{ (kW)} \times 8{,}760 \text{ (hr/year)} = 908{,}412 \text{ kW-hr/year}$$

[1] U.S. EPA. 2002a. *Cost Methodology Report for Animal Feeding Operations*. Washington, DC. December 2002.

ERG estimates the energy savings associated with Option 6 by calculating the difference between the electrical requirements before and after the installation of the digester using Equation H-2.

$$\text{Energy Savings (kW-hr/year)} = \text{(Annual Farm Energy, Baseline - Annual Farm Energy, Option 6) (kW-hr/year)} \qquad \text{(H-2)}$$

Using the annual farm energy requirements at baseline and under Option 6 calculated above and Equation H-2, the energy savings for the flush dairy model farm are:

$$\text{Energy Savings (kW-hr/year)} = (1{,}396{,}344 - 908{,}412) \text{ (kW-hr/year)} = 487{,}932 \text{ kW-hr/year}$$

Therefore, an energy benefit of 487,932 kW-hr/year is expected for this model farm.

Industry-level results for each animal type are simply calculated as the model farm results multiplied by the number of facilities (as presented in Section 6).

Table H-1										
FarmWare Parameters	**Swine - Large 2**									
Animal	GF	GF	GF	GF	GF	FF	FF	FF	FF	FF
Type	Pit	Pit	Lag	Lag	Evap	Pit	Pit	Lag	Lag	Evap
Region	MA	MW	MA	MW	CE	MA	MW	MA	MW	CE
Avg head	8893	10029	8893	10029	29389	17118	13819	17118	13819	8298
Sows	-	-	-	-	-	2260	1824	2260	1824	1095
County, state	SA, NC	BO, IA	SA, NC	BO, IA	BE, UT	SA, NC	BO, IA	SA, NC	BO, IA	BE, UT
Manure collection	pull plug	pull plug	flush to lagoon	flush to lagoon	flush to lagoon	scrape/mix	pull plug	flush to lagoon	flush to lagoon	flush to lagoon
Watershed runoff	N, w/ HR	N, w/ HR	N, w/ HR	N, w/ HR	N, w/HR	N	N	N	N	N
New anaerobic cell	yes	yes	yes	yes	yes	no	yes	yes	yes	yes
Covered lagoon digester	yes	yes	yes	yes	yes	no	yes	yes	yes	yes
Complete mix digester	no	no	no	no	no	yes	no	no	no	no
Storage tank	no	no	no	no	no	yes	no	no	no	no
Storage pond	yes	yes	no	no	no	yes	yes	no	no	no

Table H-2										
FarmWare Parameters	**Swine - Large 1**									
Animal	GF	GF	GF	GF	GF	FF	FF	FF	FF	FF
Type	Pit	Pit	Lag	Lag	Evap	Pit	Pit	Lag	Lag	Evap
Region	MA	MW	MA	MW	CE	MA	MW	MA	MW	CE
Avg head	3554	3417	3554	3417	3455	8893	10029	8893	10029	29389
Sows	-	-	-	-	-	1174	1324	1174	1324	3880
County, state	SA, NC	BO, IA	SA, NC	BO, IA	BE, UT	SA, NC	BO, IA	SA, NC	BO, IA	BE, UT
Manure collection	pull plug	pull plug	flush to lagoon	flush to lagoon	flush to lagoon	pull plug	pull plug	flush to lagoon	flush to lagoon	flush to lagoon
Watershed runoff	N, w/ HR	N, w/ HR	N, w/ HR	N, w/ HR	N, w/HR	N	N	N	N	N
New anaerobic cell	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Covered lagoon digester	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Complete mix digester	no	no	no	no	no	no	no	no	no	no
Storage tank	no	no	no	no	no	no	no	no	no	no
Storage pond	yes	yes	no	no	no	yes	yes	no	no	no

Figure H-1

FarmWare Assessment

for

FARM NAME

Flush 1430

This assessment is provided as a first step in evaluating the financial and technical potential of methane recovery technology at FARM NAME and is to be considered preliminary and used as guidance only. It is imperative that a detailed final feasibility assessment be completed by qualified agricultural and energy engineers prior to any design, construction, or purchase of materials. The AgSTAR Handbook may be used for additional reference and guidance on the process.

Prepared by:
<<User Name>>
<<User Company>>
<<User Address>>

Please submit one copy of this report to:
AgSTAR Program; U.S. EPA (6202J); 401 M Street, S.W.; Washington, DC 20460

Summary

FARM NAME is a 1,430 milk cows freestall dairy located in Tulare County, California. Electric service is provided by UTILITY NAME. Electricity expenses over the past 12 months billing history were $82,056 and propane purchases were $12,771.

This farm evaluation is for a Double Cell Lagoon methane recovery system. The capital cost of this system is estimated to be $218,028. The financial performance of this option is based on:

1. the past 12 month billing history from UTILITY NAME and annual propane costs; and
2. projected energy savings under Default and propane savings from heat recovery.

The evaluation uses an 85% operational efficiency, $0.015 kWh O&M, 0% downpayment, and a 10 year system life. The financial performance of this evaluation is summarized below.

Table 1: Financial Results of Methane Recovery

Methane Recovery Option	Installation Cost ($)	Annual Savings ($)	Simple Payback (yrs)	Internal Rate of Return (%)	Net Present Value ($)
Double Cell Lagoon	218,028	66,190	4.0	<0	105,343

Detailed Assessment

Farm Description

FARM NAME is a 1,430 milk cows freestall dairy located in Tulare County, California. The remaining animal population levels as well as the time spent in housing are summarized below:

Table 2: Standing Animal Populations and Time Spent in Housing (Hours)

Type of Housing	Cow-Lac	Cow-Dry	Heifer	Calf	Bull
Number of Animals	1,430	0	429	429	0
Parlor	4	0	0	0	0
Free Stall Barn	20	0	0	0	0
Feed Apron	0	0	0	0	0
Drylot	0	0	24	24	0
Barn	0	0	0	0	0

Manure Management

The selected methane recovery system at this farm is a Double Cell Lagoon. A total of 19,296 gallons of manure and 186,378 gallons of water enter the system on a daily basis. The total solids content of the influent manure stream is 0.6%. These characteristics are summarized below:

Table 3: Manure and Water Amounts Entering the Methane Recovery Facility, Gallons

Facility	Total Manure (gal)	Total Water (gal)	Total Influent (gal)
Parlor	3,216	43,378	46,594
Free Stall Barn	16,080	143,000	159,080
Process Water	0	0	0
Total	19,296	186,378	205,674

Energy Use

Electric Service at this farm provided by UTILITY NAME. FARM NAME is currently on a Default rate schedule. Electrical costs over the past 12 month billing period on Default were $82,056. Propane costs were also based on a 12 month billing period and are estimated to be $12,771. Figure 1 illustrates the farm's monthly energy costs and Figure 2 illustrates the farm's monthly energy (kWh) and demand (kW).

Figure 1: Energy Costs

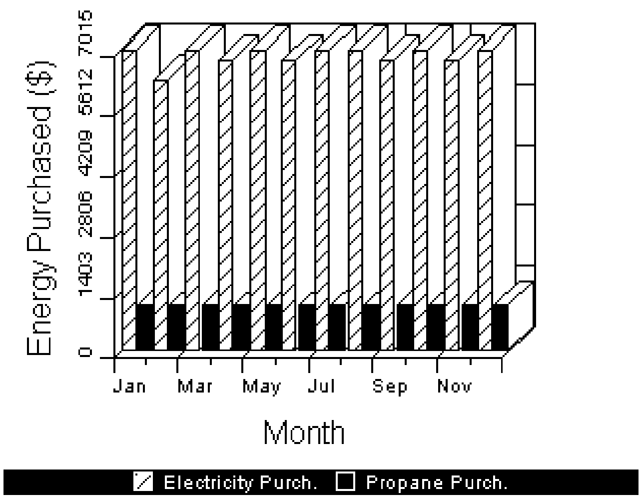
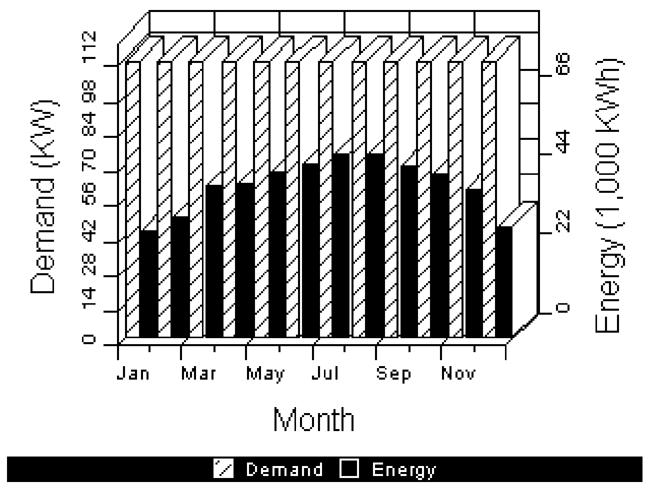


Figure 2: Energy and Demand



Methane Recovery

The chosen methane recovery option for FARM NAME is a Double Cell Lagoon with the following parameters:

Table 4: Methane Recovery Facility Parameters

Primary Lagoon Parameters	
Length (ft)	285
Width (ft)	285
Depth (ft)	20
Side slope (ft)	2
Diameter (ft)	0
Loading Rate (lbVS/1,000 cf/day)	8
Hydraulic Retention Time (days)	42
Volume (cubic ft)	1,211,167
Surface Area (square ft)	81,225

A cover is placed over 100% of this system.

Energy Use and Financial Performance

The Double Cell Lagoon is estimated to produce biogas at an average rate of 31,763 cubic feet/day. This biogas may be used to power an engine generator with an estimated rating of 112 kW. Additional biogas uses may include energy for hot water, space heat, or refrigeration. These options are not analyzed in FarmWare.

With the Double Cell Lagoon, this farm could potentially save up to $54,799 per year in current electrical costs . This would provide approximately 67% of the annual electrical demand. Detailed monthly energy estimations with and without the Double Cell Lagoon are summarized in the figures below:

Figure 3: Comparative Demand

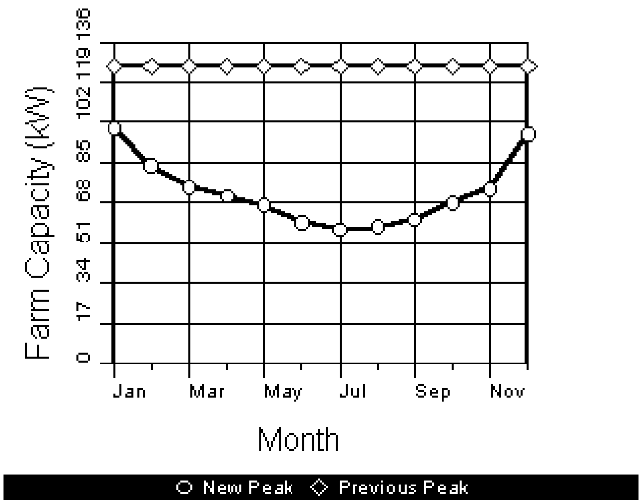


Figure 4: Comparative Energy

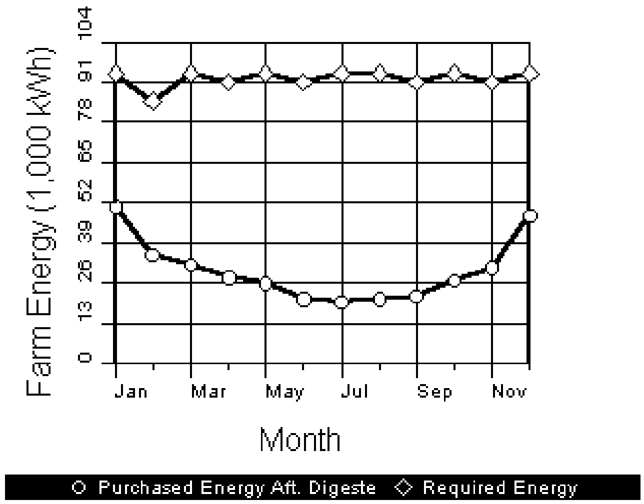
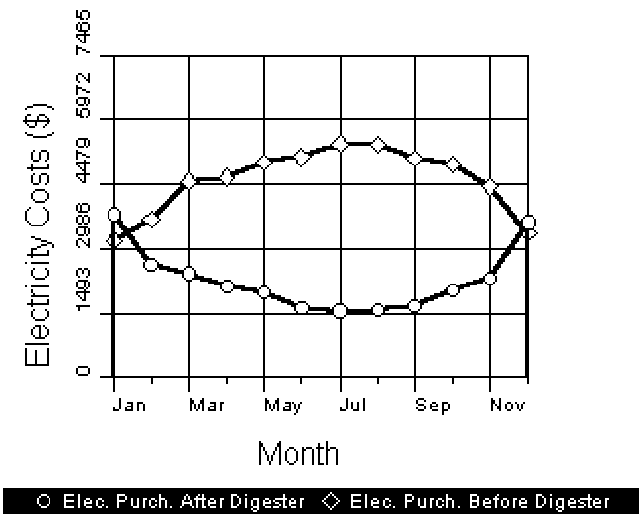


Figure 5: Electric Revenue



Cost Benefit Analysis

The total cost of the Double Cell Lagoon at this farm is estimated to be $218,028. Estimated annual returns from displaced electrical costs are $66,190. The payback on the investment of this project is estimated to be 4.0 years. Additionally, the internal rate of return (IRR) is estimated to be <0% and the net present value (NPV) is estimated to be $105,343. This very positive NPV indicates that the selected methane recovery option should be profitable. A complete summary of the estimated costs and benefits are detailed below:

Table 5: Cost and Benefit Analysis

	Electricity and Hot Water
COSTS	
Sld Separator	0
Primary Lagoon	42,651
Lagoon Cover	68,327
Secondary Storage	0
Generator Bldg.	82,050
Engineering	25,000
TOTAL COSTS	218,028
BENEFITS	
Annual 'On-Farm' Energy Savings	54,799
Propane Savings	11,391
Other Benefits	0
Odor Benefits	0
TOTAL BENEFITS	66,190

Table 6: Financial Performance

Project Life (years)	10
Downpayment (%)	0
Loan Rate (%)	7
Discount Rate (%)	7
Tax Rate (%)	35
Depreciation Type	SYD
O&M Elect. ($/kWh)	0.015
Energy Cost Growth (%/yr)	5.0
NPV ($)	105,343
Payback (years)	4.0
IRR (%)	<0